US009459000B2

(12) **United States Patent**
Ramer et al.

(10) **Patent No.: US 9,459,000 B2**
(45) **Date of Patent: Oct. 4, 2016**

(54) **THERMAL CONDUCTIVITY AND PHASE TRANSITION HEAT TRANSFER MECHANISM INCLUDING OPTICAL ELEMENT TO BE COOLED BY HEAT TRANSFER OF THE MECHANISM**

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(72) Inventors: **David P. Ramer**, Reston, VA (US); **Jack C. Rains, Jr.**, Herndon, VA (US)

(73) Assignee: **ABL IP HOLDING LLC**, Conyers, GA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/249,736**

(22) Filed: **Apr. 10, 2014**

(65) **Prior Publication Data**

US 2014/0217272 A1 Aug. 7, 2014

Related U.S. Application Data

(63) Continuation of application No. 13/221,244, filed on Aug. 30, 2011, now Pat. No. 8,710,526.

(51) **Int. Cl.**
H01L 29/06 (2006.01)
F21V 29/00 (2015.01)
(Continued)

(52) **U.S. Cl.**
CPC ***F21V 29/006*** (2013.01); ***F28D 15/02*** (2013.01); ***F28D 15/046*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC H01L 33/648; H01L 31/052; H01L 2224/48091; H01L 2224/48247; H01L 2224/73265; F21V 29/006; F21V 29/506; F28D 15/02; F28D 15/046; H01S 5/02423; Y02E 10/50; F21K 9/135; F21Y 2101/02; F21Y 2101/025; F21Y 2105/008
See application file for complete search history.

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Entire prosecution history of U.S. Appl. No. 14/268,504, entitled "Optical/Electrical Transducer Using Semiconductor Nanowire Wicking Structure in a Thermal Conductivity and Phase Transition Heat Transfer Mechanism," filed May 2, 2014.
(Continued)

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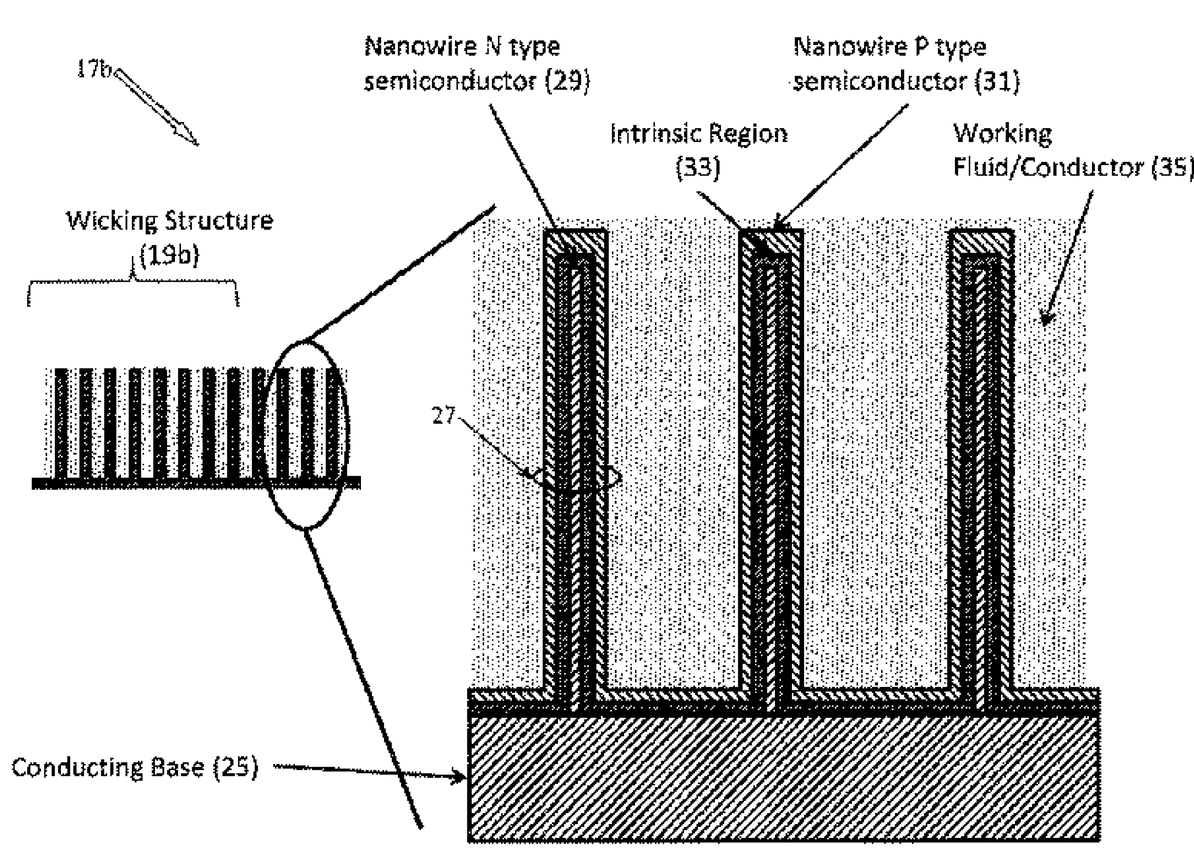
(74) *Attorney, Agent, or Firm* — RatnerPrestia

(57) **ABSTRACT**

A thermal conductivity and phase transition heat transfer mechanism incorporates an active optical element. Examples of active optical elements include various phosphor materials for emitting light, various electrically driven light emitters and various devices that generate electrical current or an electrical signal in response to light. The thermal conductivity and phase transition between evaporation and condensation, of the thermal conductivity and phase transition heat transfer mechanism, cools the active optical element during operation. At least a portion of the active optical element is exposed to a working fluid within a vapor tight chamber of the heat transfer mechanism. The heat transfer mechanism includes a member that is at least partially optically transmissive to allow passage of light to or from the active optical element and to seal the chamber of the heat transfer mechanism with respect to vapor contained within the chamber.

12 Claims, 19 Drawing Sheets



(51) **Int. Cl.**

H01L 31/024	(2014.01)
H01L 31/052	(2014.01)
H01L 33/64	(2010.01)
F28D 15/02	(2006.01)
F28D 15/04	(2006.01)
H01S 5/024	(2006.01)
F21K 99/00	(2016.01)
F21Y 101/02	(2006.01)
F21Y 105/00	(2016.01)
F21V 29/506	(2015.01)

(52) **U.S. Cl.**

CPC ***H01L 31/024*** (2013.01); ***H01L 31/052*** (2013.01); ***H01L 33/648*** (2013.01); ***H01S 5/02423*** (2013.01); *F21K 9/135* (2013.01); *F21V 29/506* (2015.01); *F21Y 2101/02* (2013.01); *F21Y 2101/025* (2013.01); *F21Y 2105/008* (2013.01); *H01L 2224/48091* (2013.01); *H01L 2224/48247* (2013.01); *H01L 2224/73265* (2013.01); *H01L 2924/12044* (2013.01); *Y02E 10/50* (2013.01)

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Entire prosecution history of U.S. Appl. No. 13/221,050, entitled "Optical/Electrical Transducer Using Semiconductor Nanowire Wicking Structure in a Thermal Conductivity and Phase Transition Heat Transfer Mechanism," filed Aug. 30, 2011.

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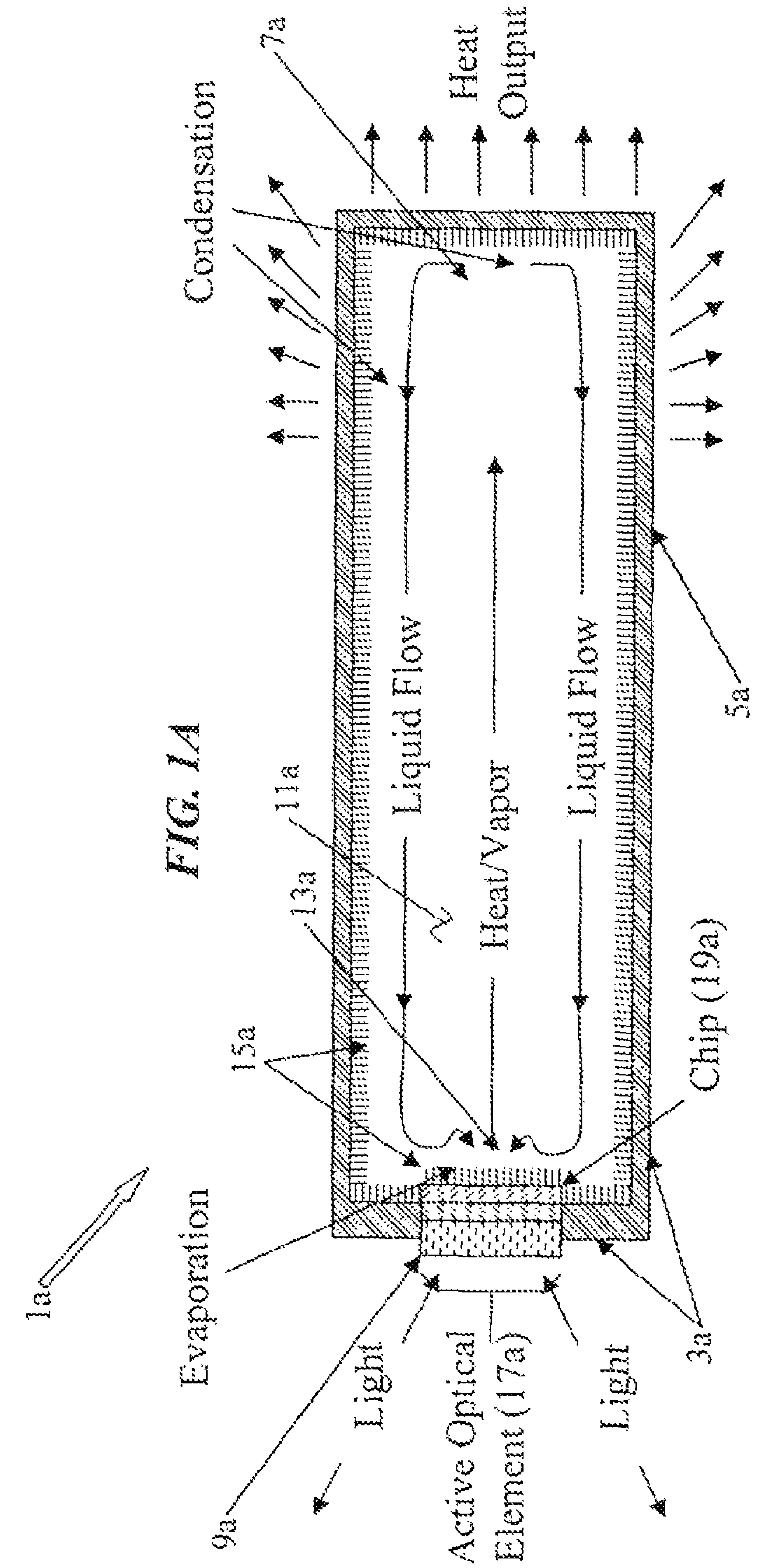
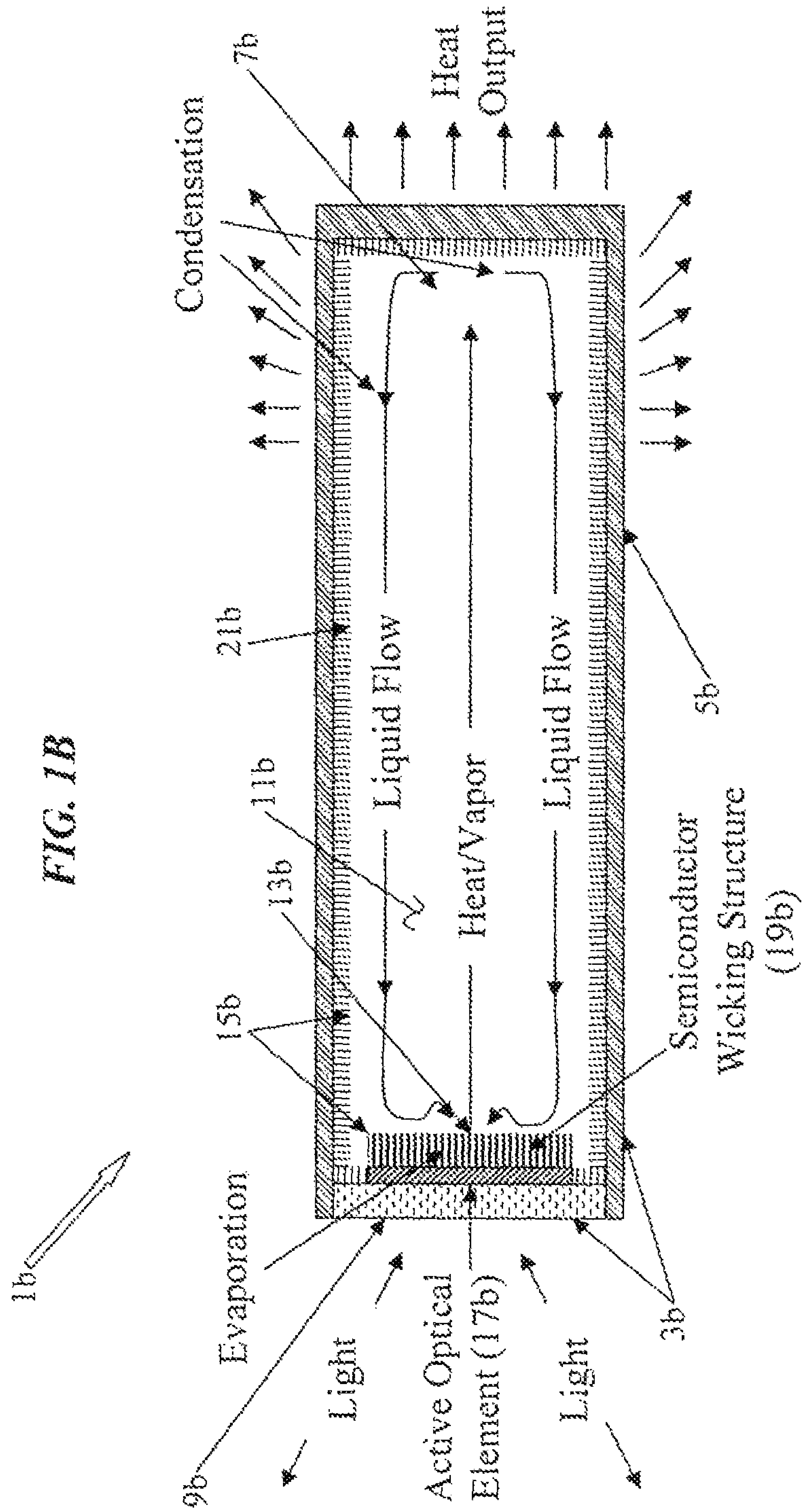
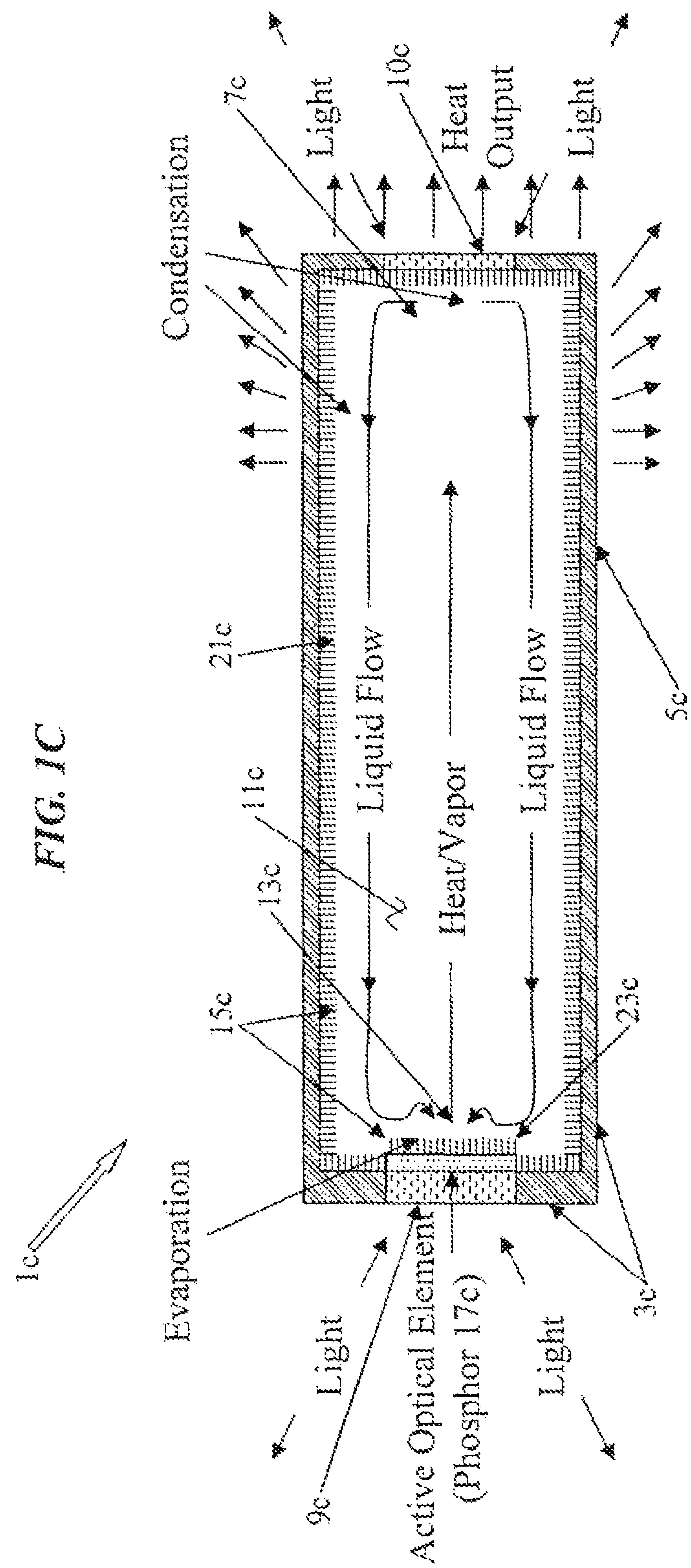

Heat
Output
Condensation
7a
Liquid Flow
Heat/Vapor
Liquid Flow
5a
11a
13a
15a
Chip (19a)
Evaporation
1a
3a
Light
Active Optical
Element (17a)
Light
9a

FIG. 1A



7b
Heat
Output
Condensation
21b
5b
Liquid Flow
Heat/Vapor
Liquid Flow
11b
13b
15b
Semiconductor
Wicking Structure
(19b)
1b
Evaporation
Light
Active Optical
Element (17b)
Light
3b
9b

FIG. 1B



1c
Evaporation
Condensation
Light
Heat Output
Light
Liquid Flow
Heat/Vapor
Liquid Flow
Active Optical Element (Phosphor 17c)
Light
Light
7c
10c
21c
5c
11c
13c
15c
23c
3c
9c

FIG. 1C

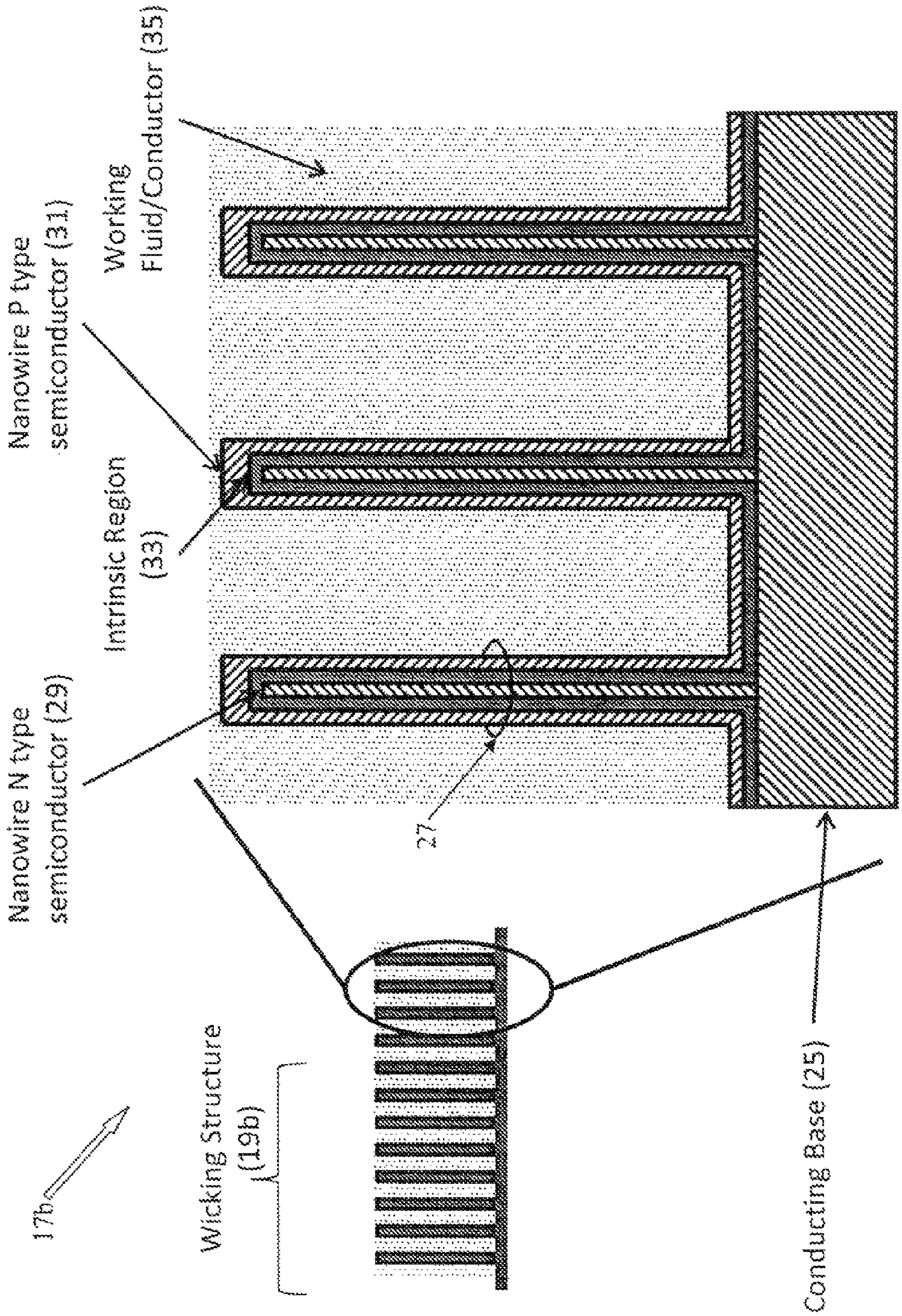

Working Fluid/Conductor (35)
Nanowire P type semiconductor (31)
Intrinsic Region (33)
Nanowire N type semiconductor (29)
27
17h
Wicking Structure (19b)
Conducting Base (25)

FIG. 2

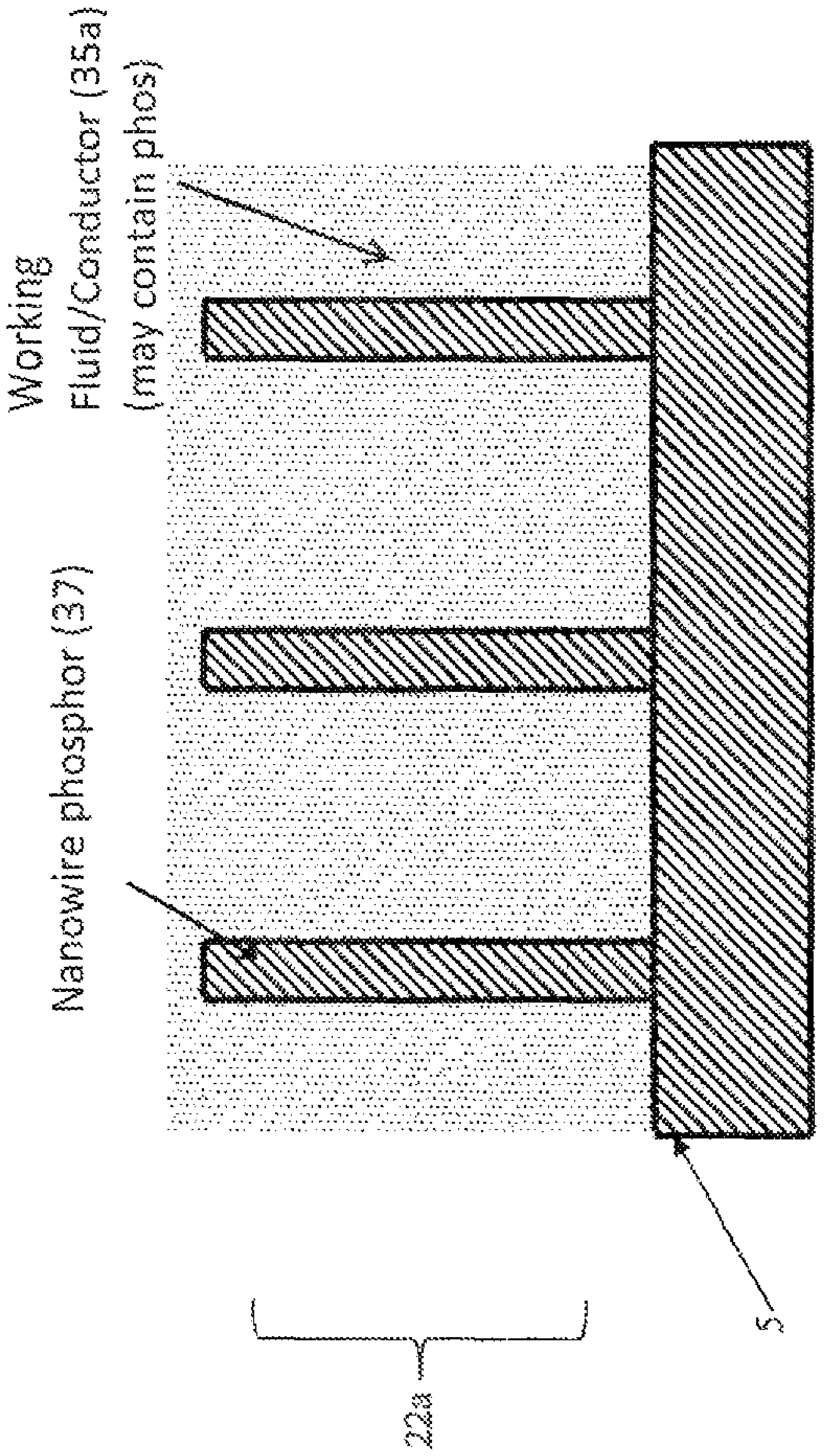

Working
Fluid/Conductor (35a)
(may contain phos)
Nanowire phosphor (37)
22a
5

FIG. 3

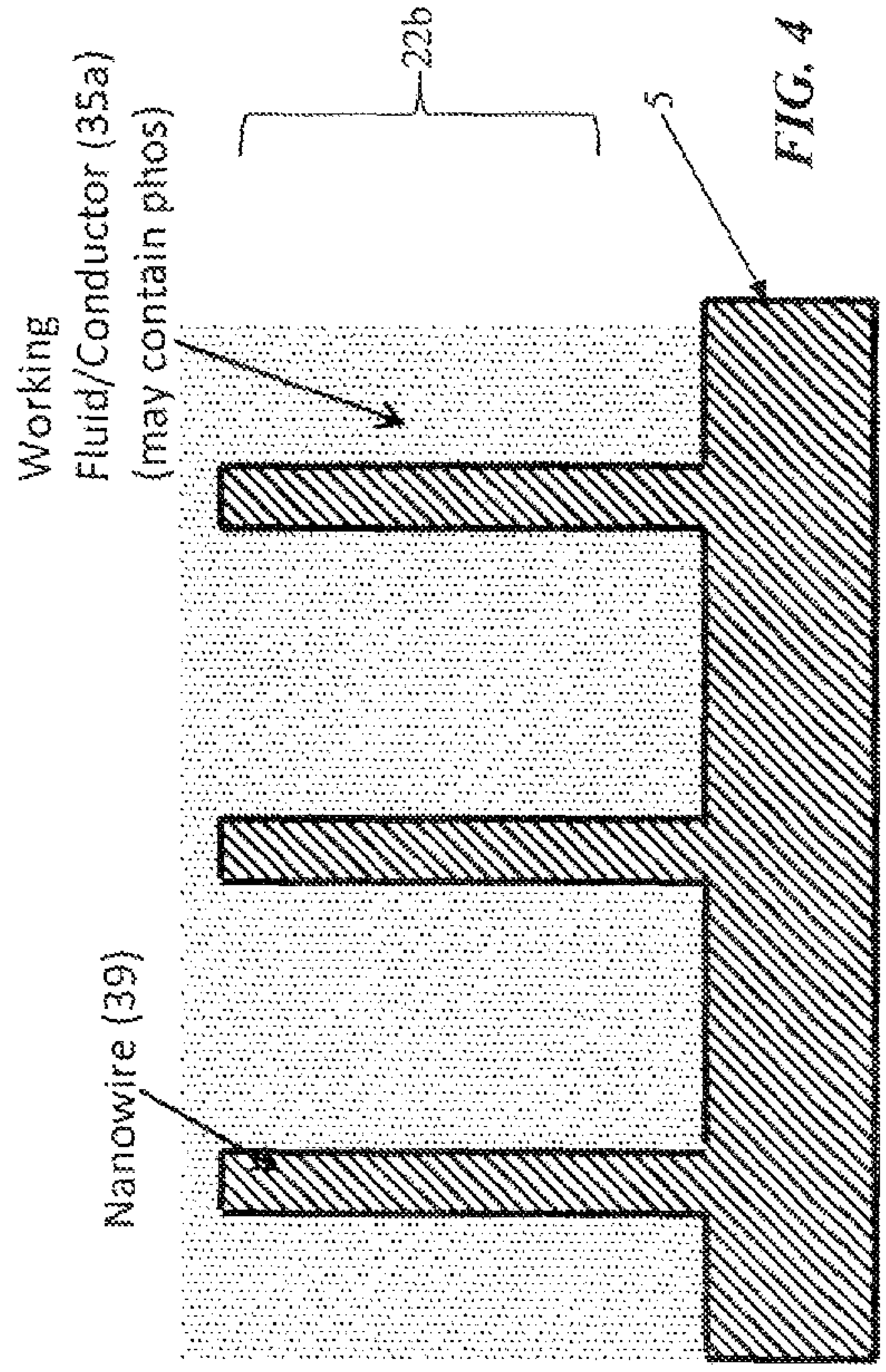
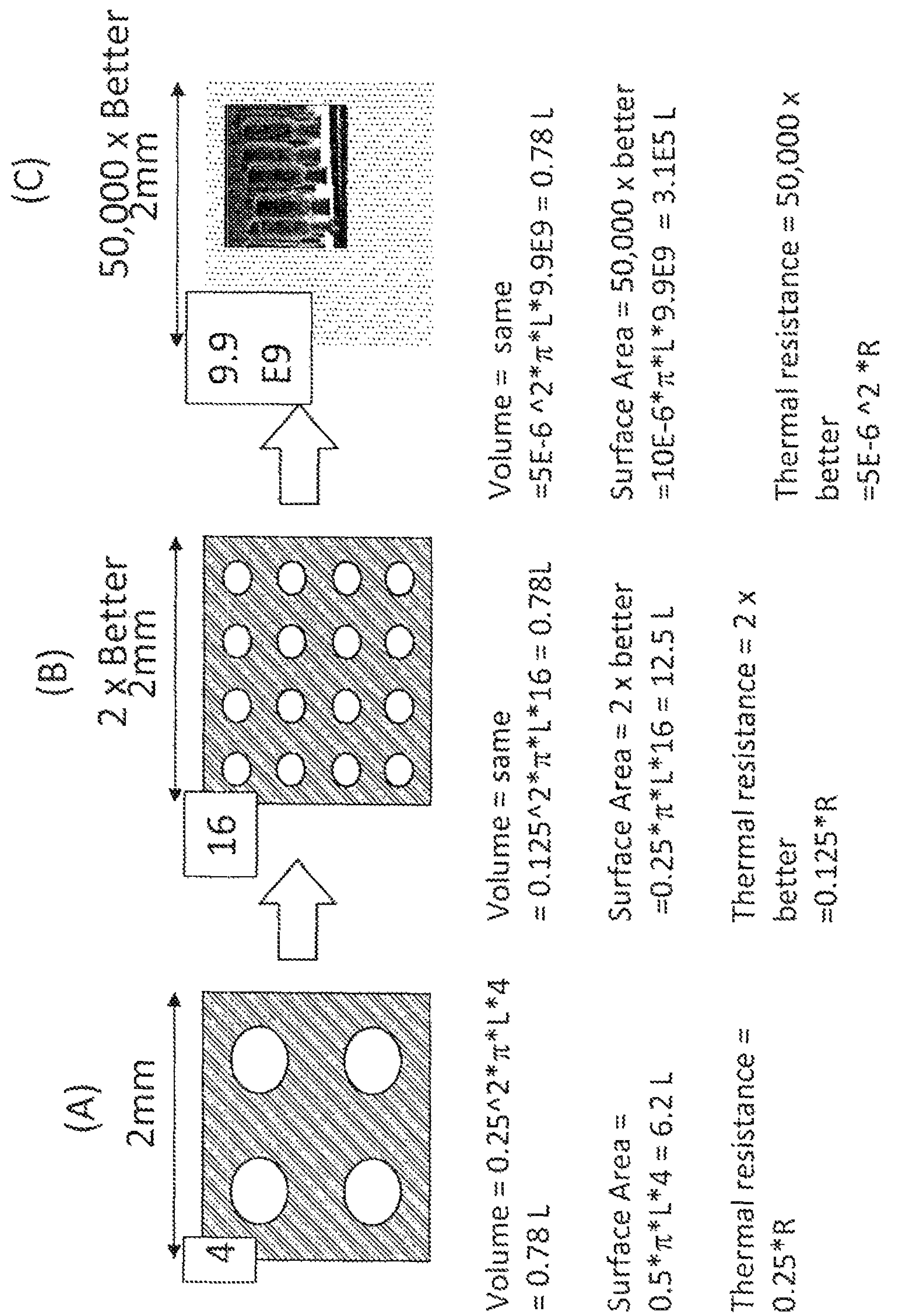

Working
Fluid/Conductor (35a)
(may contain phos)
Nanowire (39)
22b
5

FIG. 4

FIG. 5


(A)
2mm
4
Volume = 0.25^2*π*L*4
= 0.78 L
Surface Area =
0.5*π*L*4 = 6.2 L
Thermal resistance =
0.25*R
(B)
2 x Better
2mm
16
Volume = same
= 0.125^2*π*L*16 = 0.78L
Surface Area = 2 x better
=0.25*π*L*16 = 12.5 L
Thermal resistance = 2 x
better
=0.125*R
(C)
50,000 x Better
2mm
9.9
E9
Volume = same
=5E-6^2*π*L*9.9E9 = 0.78 L
Surface Area = 50,000 x better
=10E-6*π*L*9.9E9 = 3.1E5 L
Thermal resistance = 50,000 x
better
=5E-6^2*R

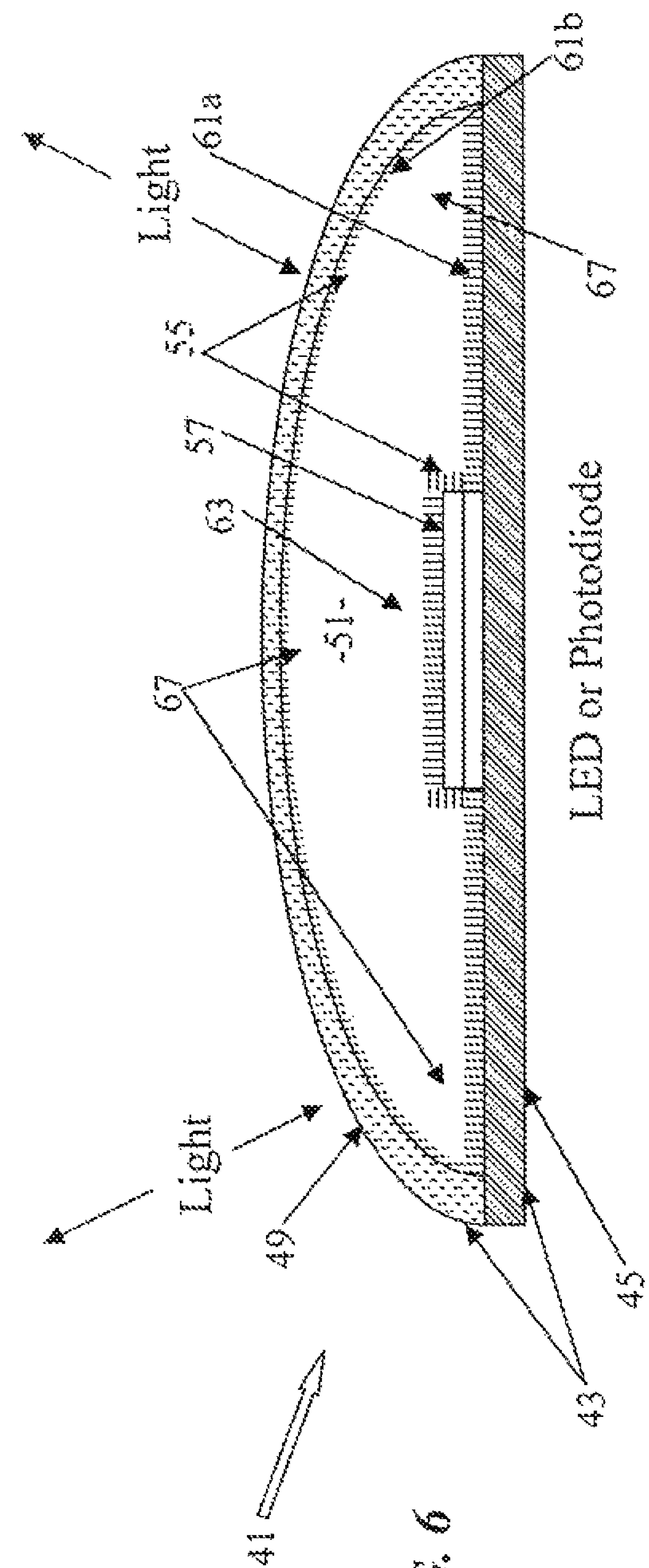

Light
61a
61b
67
55
57
63
-51-
67
LED or Photodiode
Light
49
45
43
41

FIG. 6

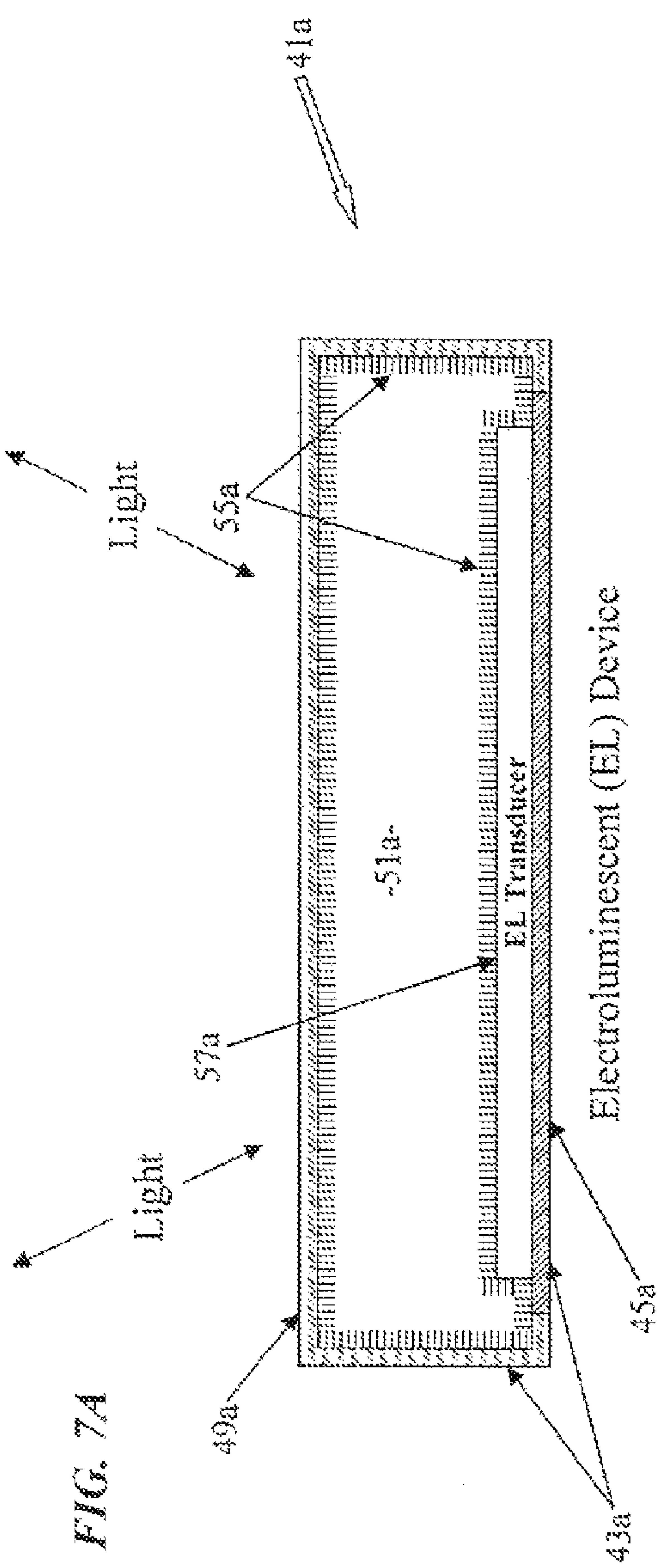

41a
Light
55a
Light
57a
-51a-
EL Transducer
Electroluminescent (EL) Device
49a
45a
43a

FIG. 7A

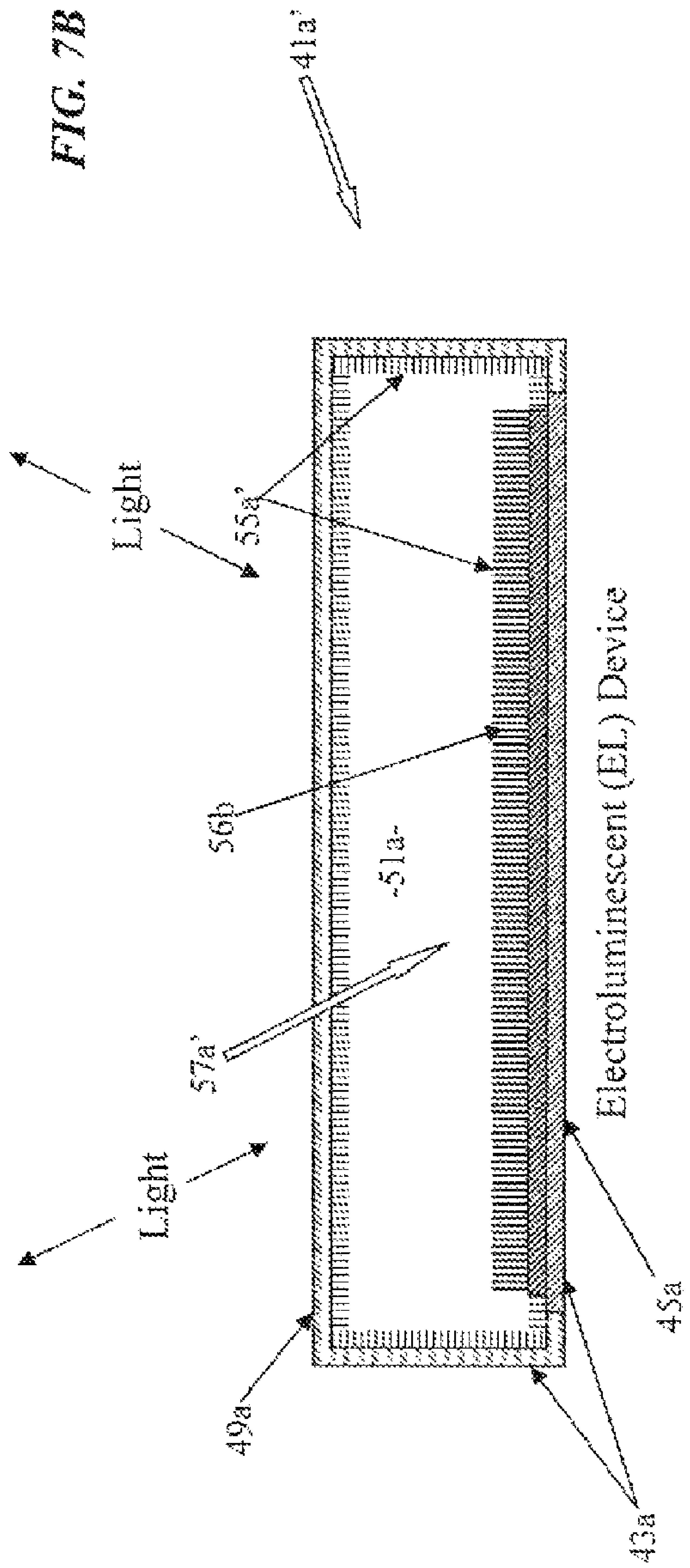

41a'
Light
55a'
56b
-51a-
57a'
Light
Electroluminescent (EL) Device
49a
45a
43a

FIG. 7B

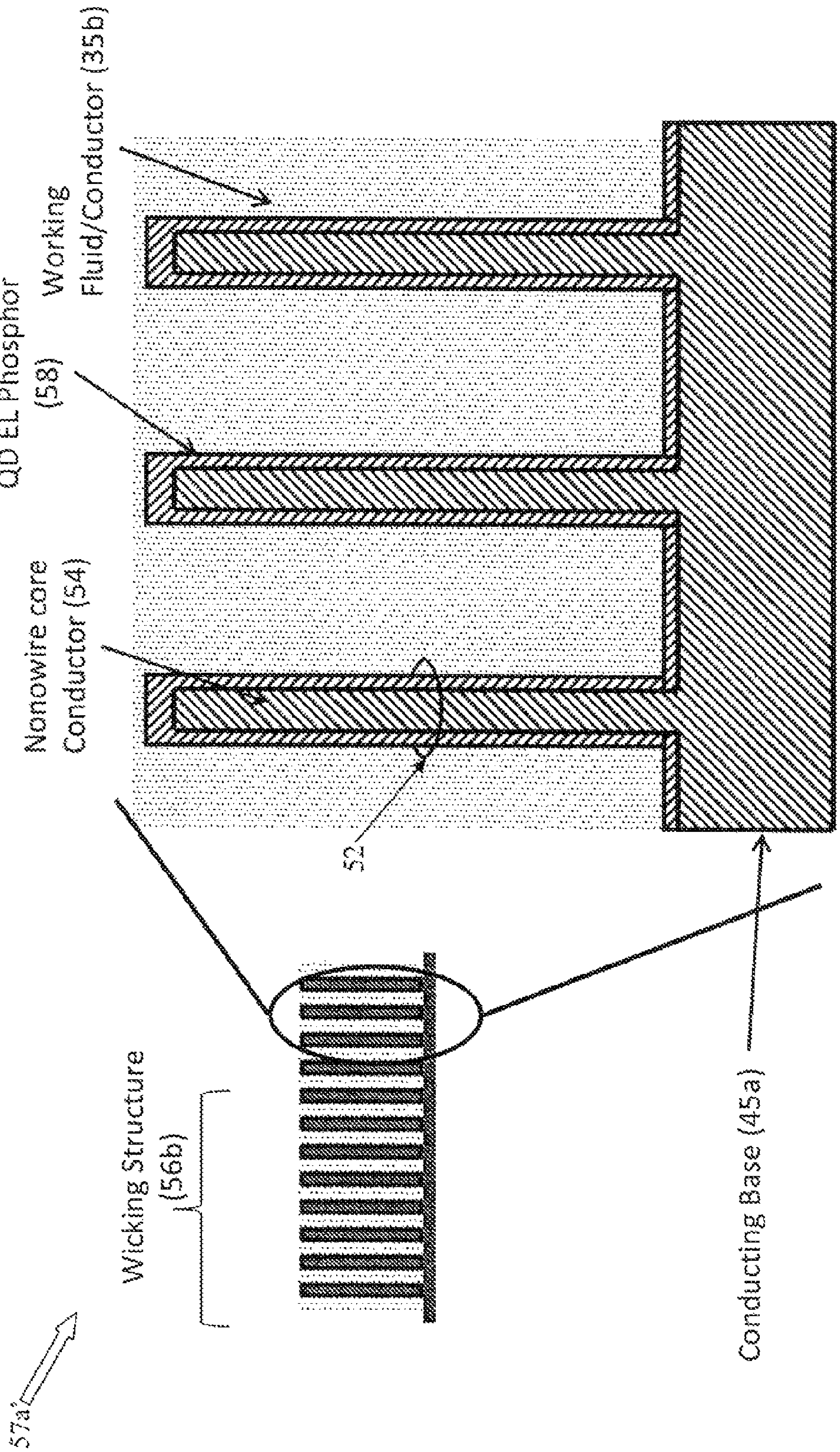

Working
Fluid/Conductor (35b)
QD EL Phosphor
(58)
Nonowire core
Conductor (54)
52
Wicking Structure
(56b)
Conducting Base (45a)
57a'

FIG. 7C

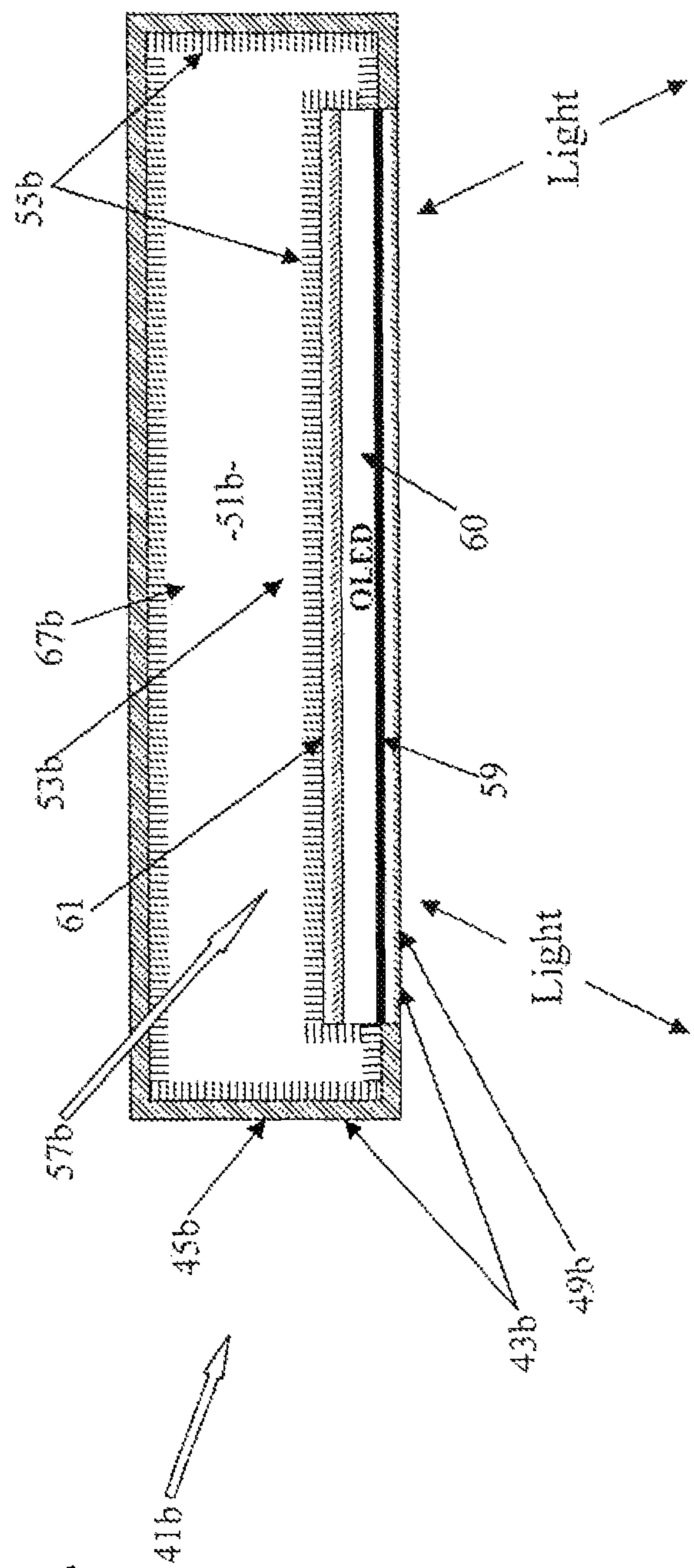


FIG. 8

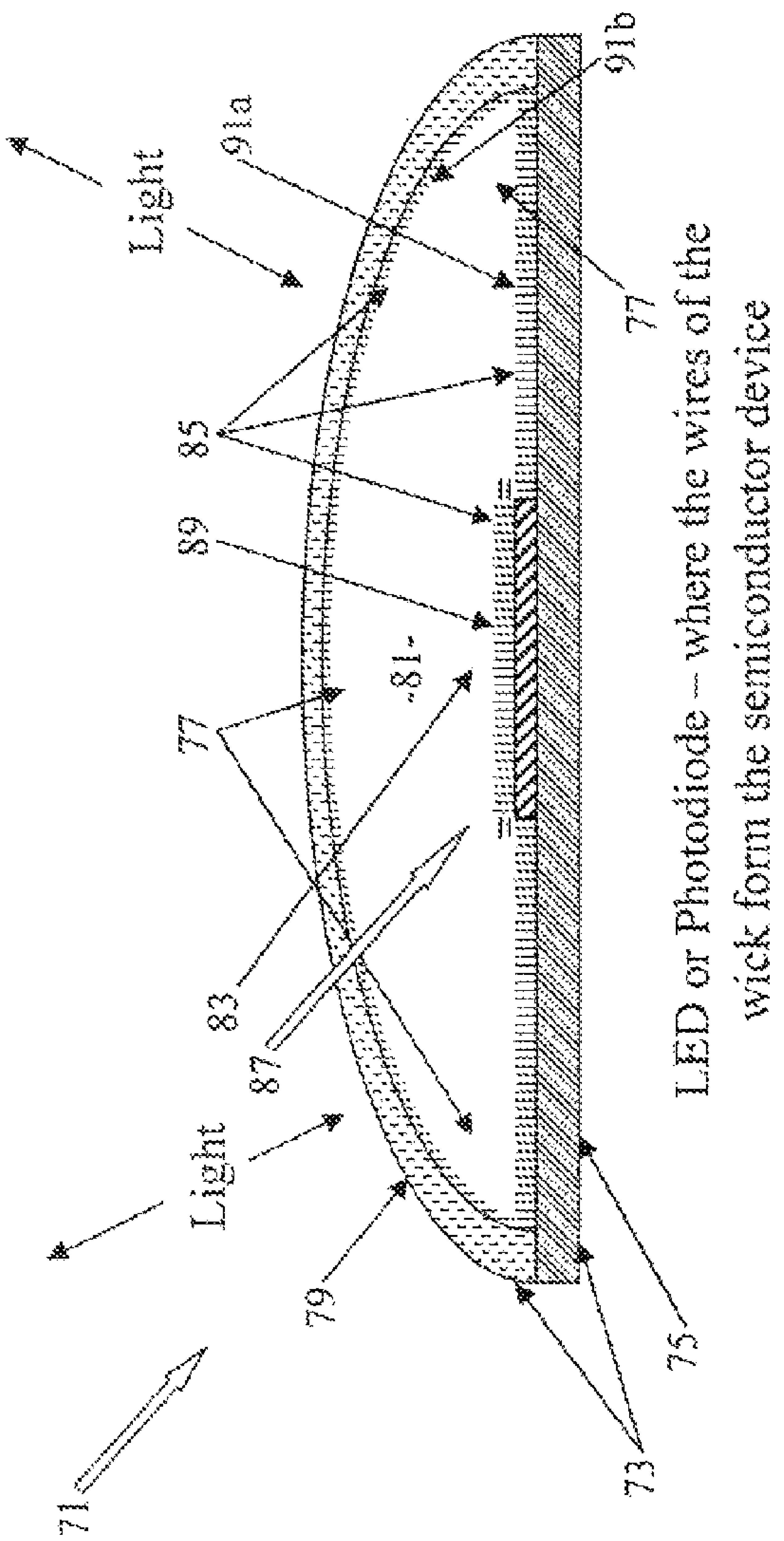

71
73
75
79
Light
87
83
77
81
89
85
Light
91a
91b
77
LED or Photodiode – where the wires of the wick form the semiconductor device

FIG. 9A

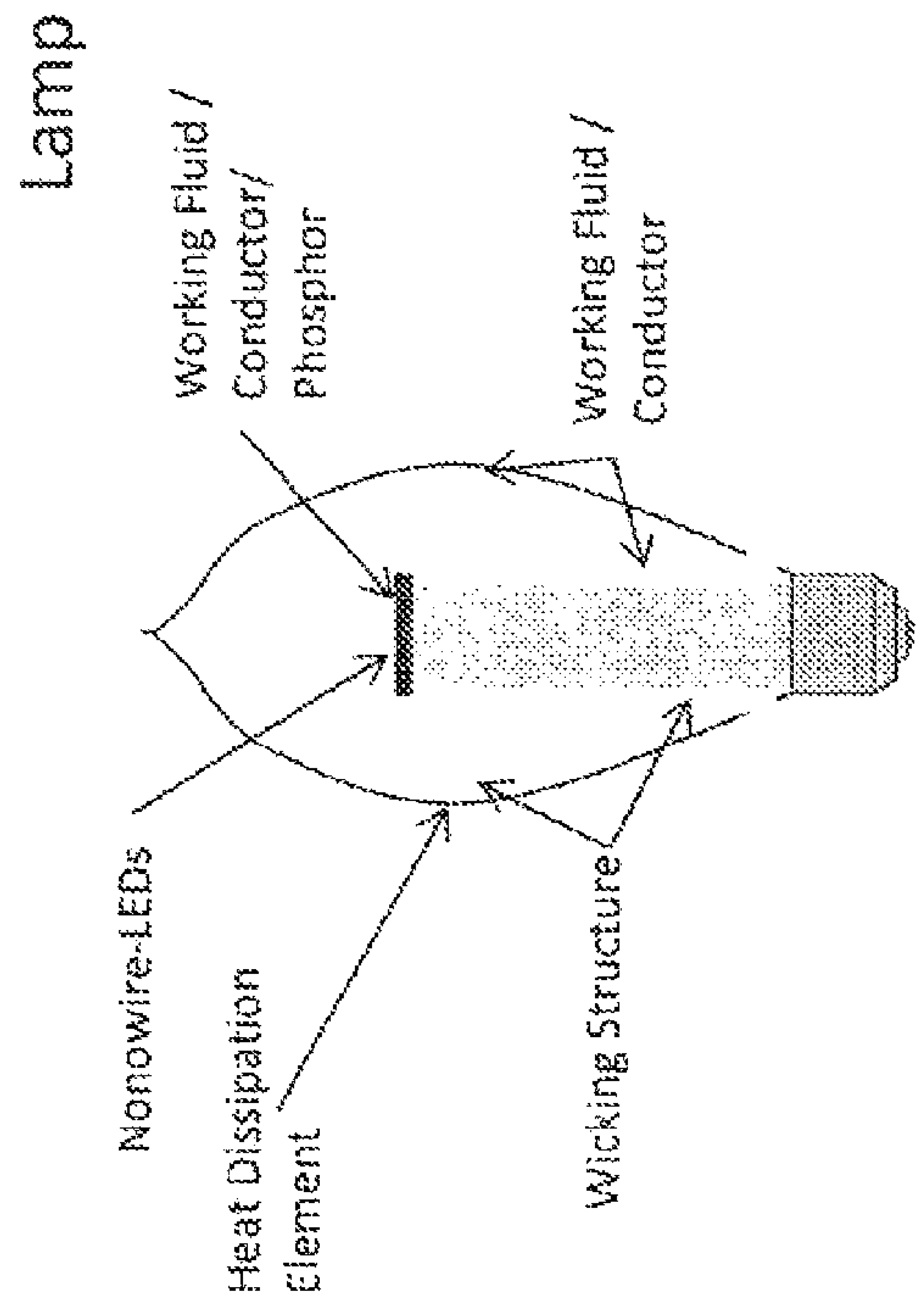

Lamp
Working Fluid / Conductor/ Phosphor
Working Fluid / Conductor
Nonowire-LEDs
Heat Dissipation Element
Wicking Structure

FIG. 9B

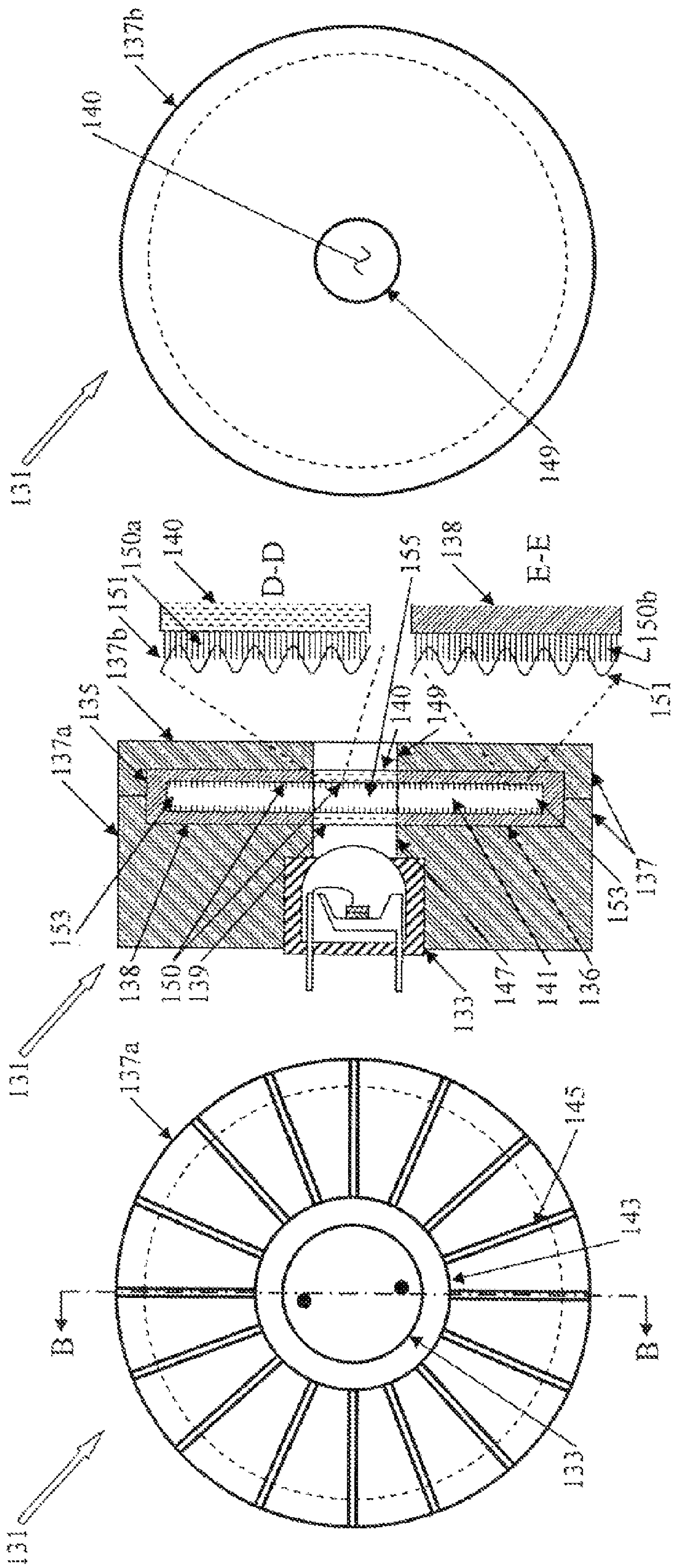


FIG. 10A

FIG. 10B

FIG. 10C

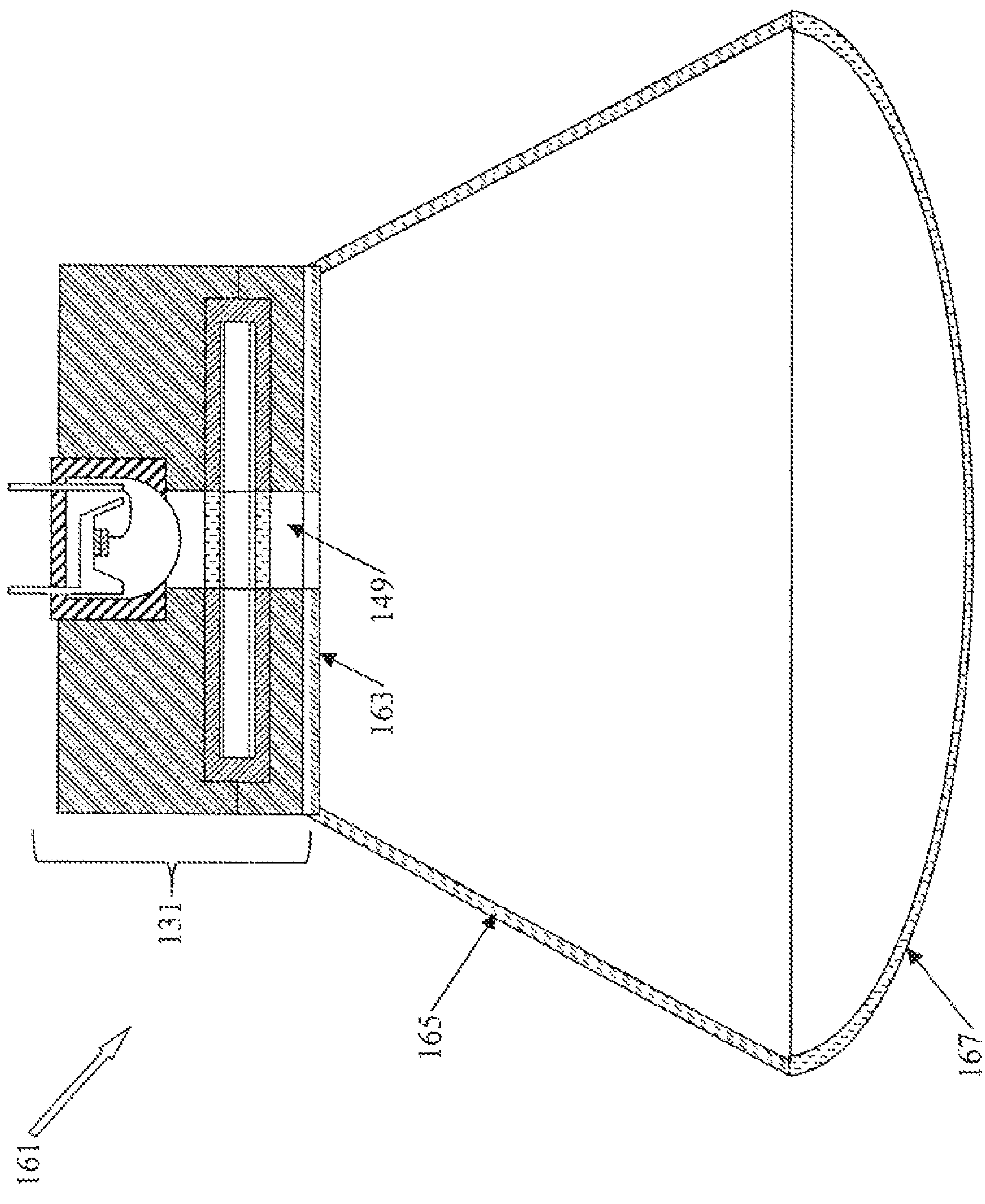


FIG. 11

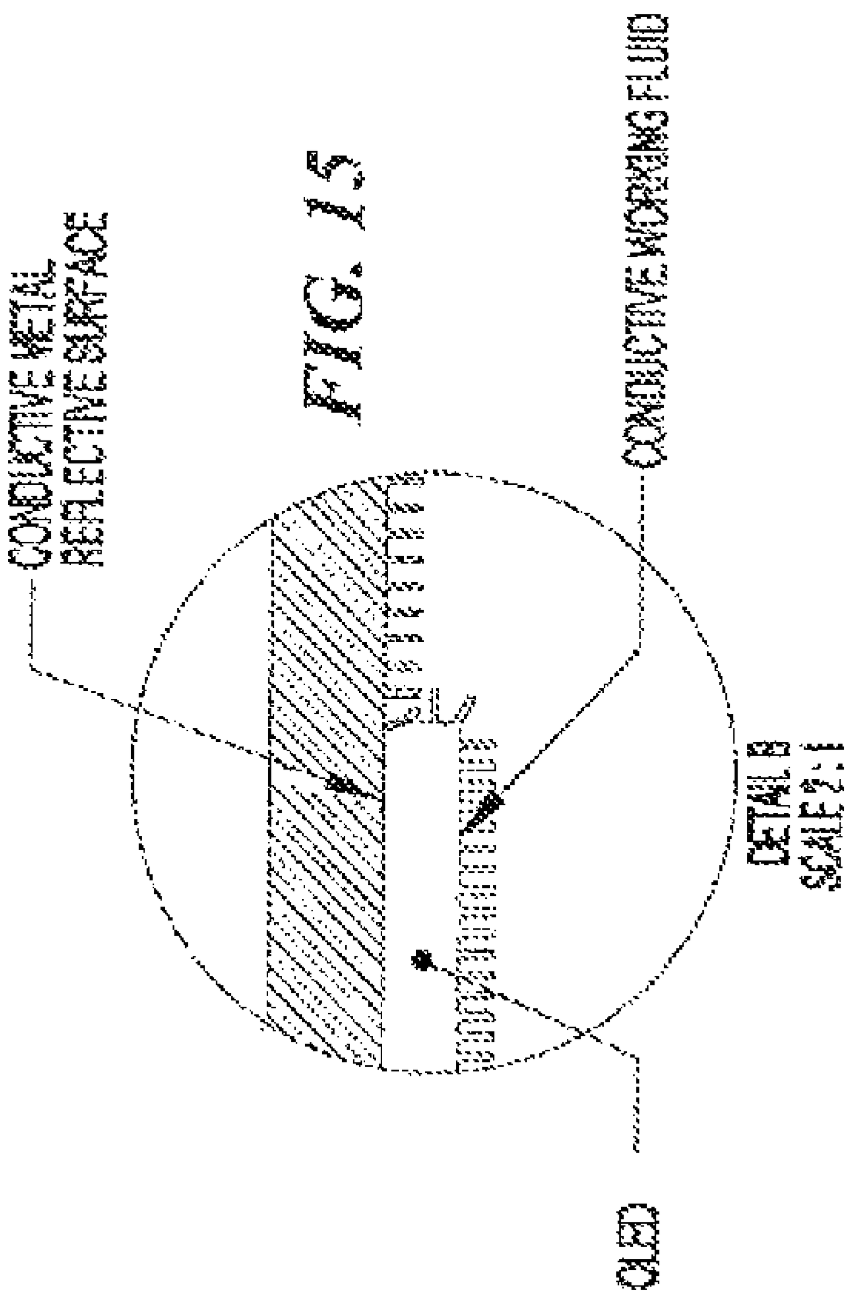


FIG. 15

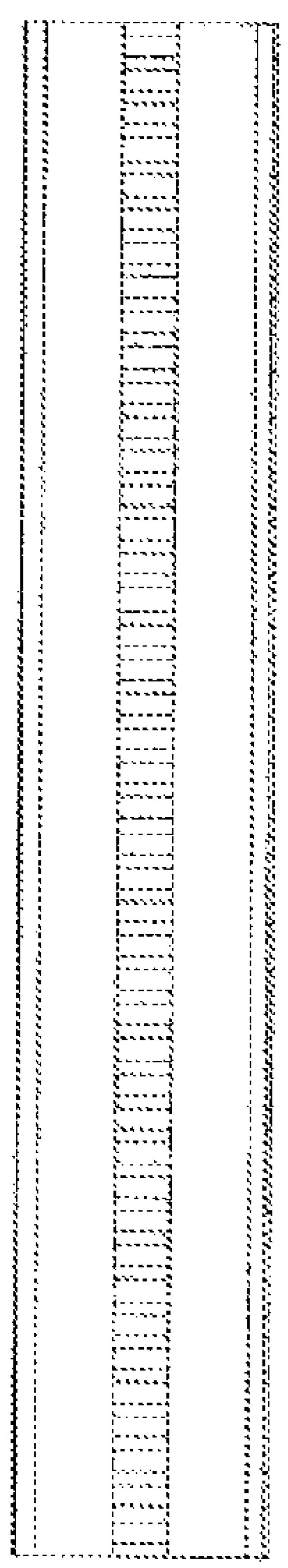


FIG. 12

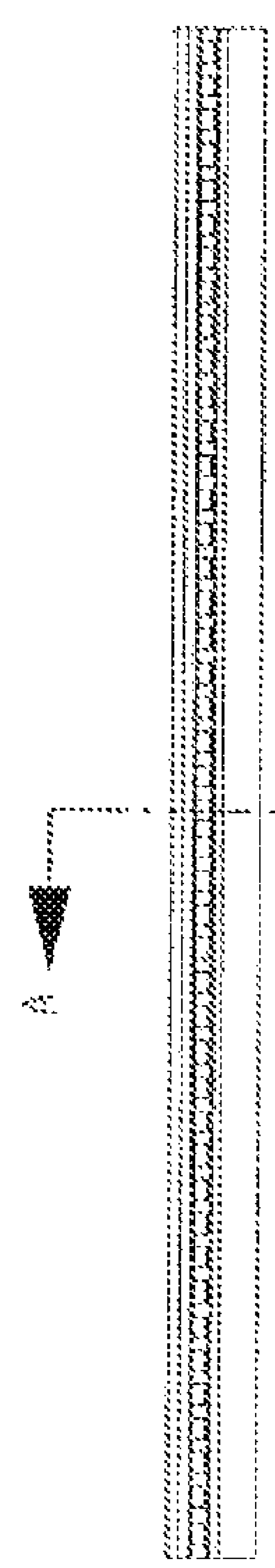
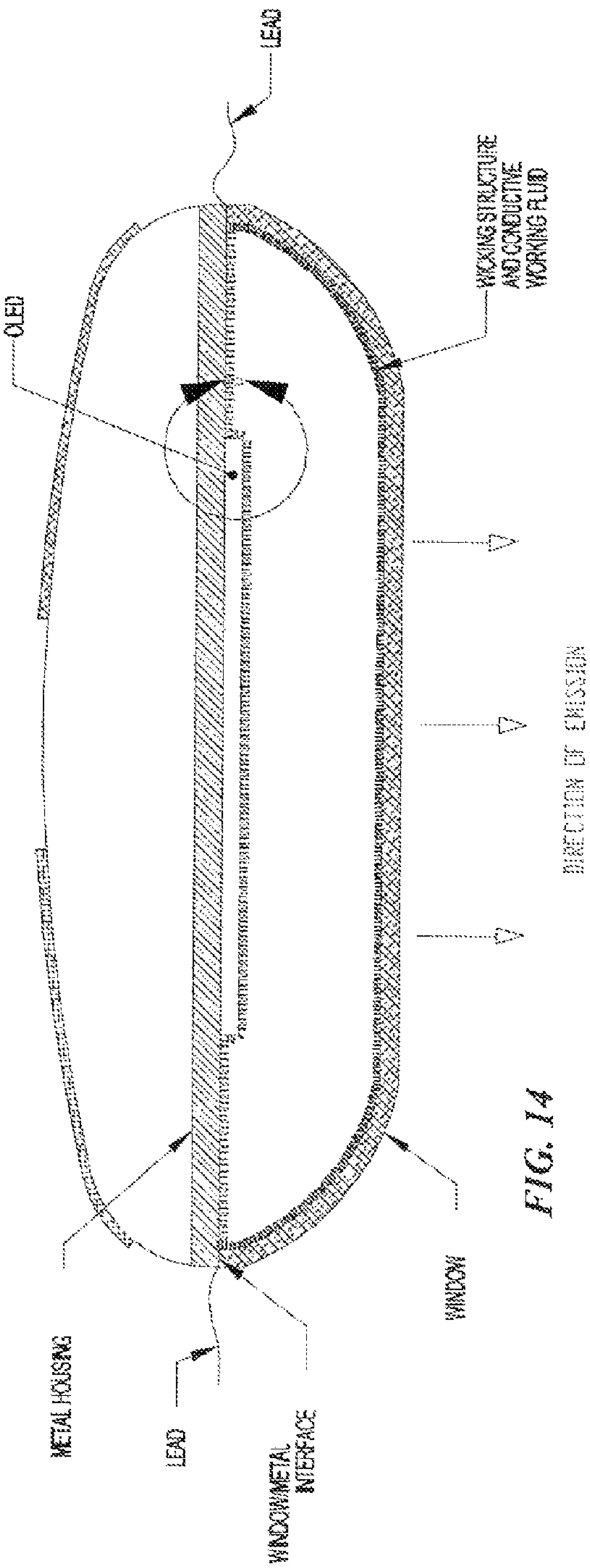


FIG. 13



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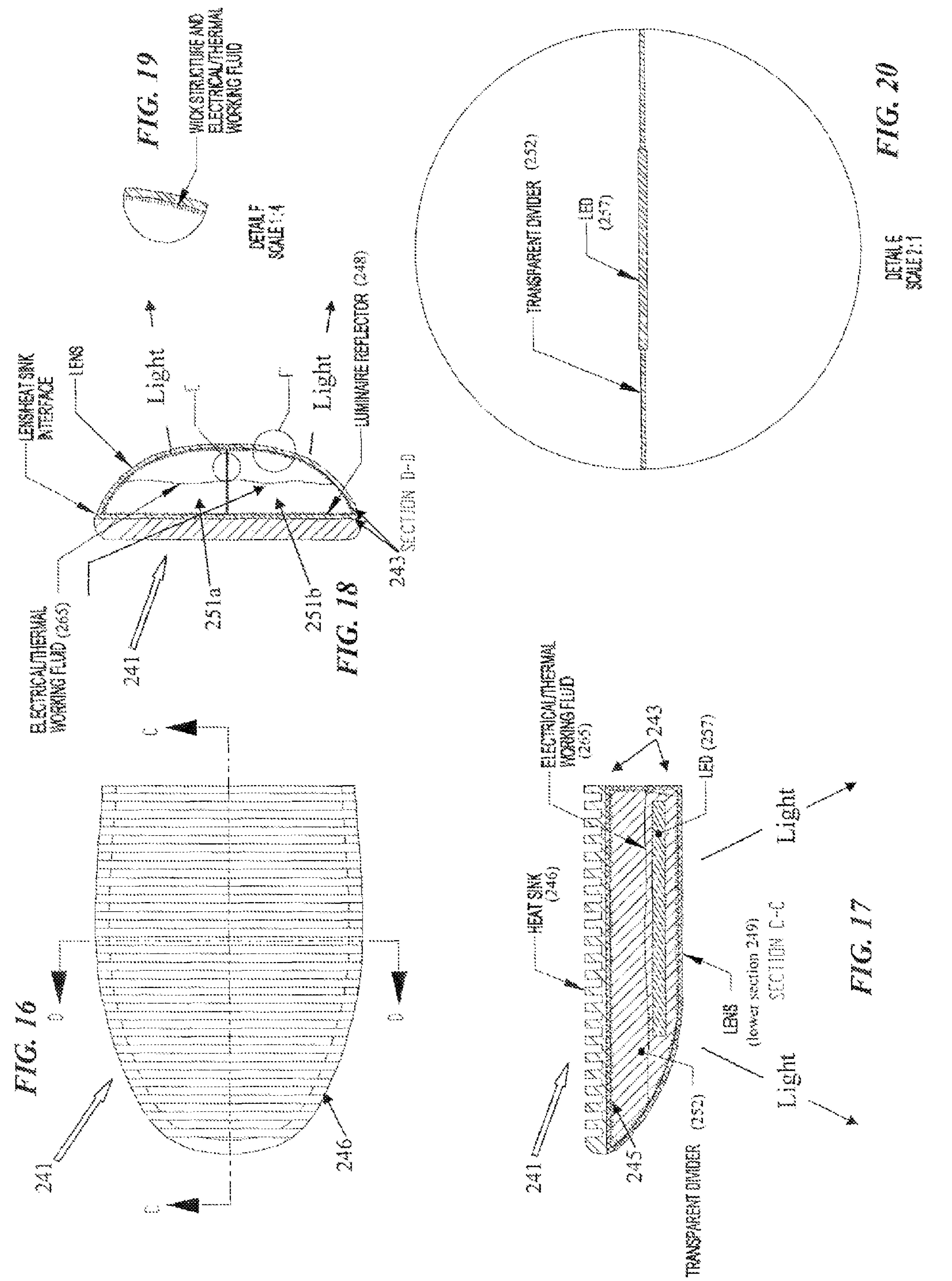


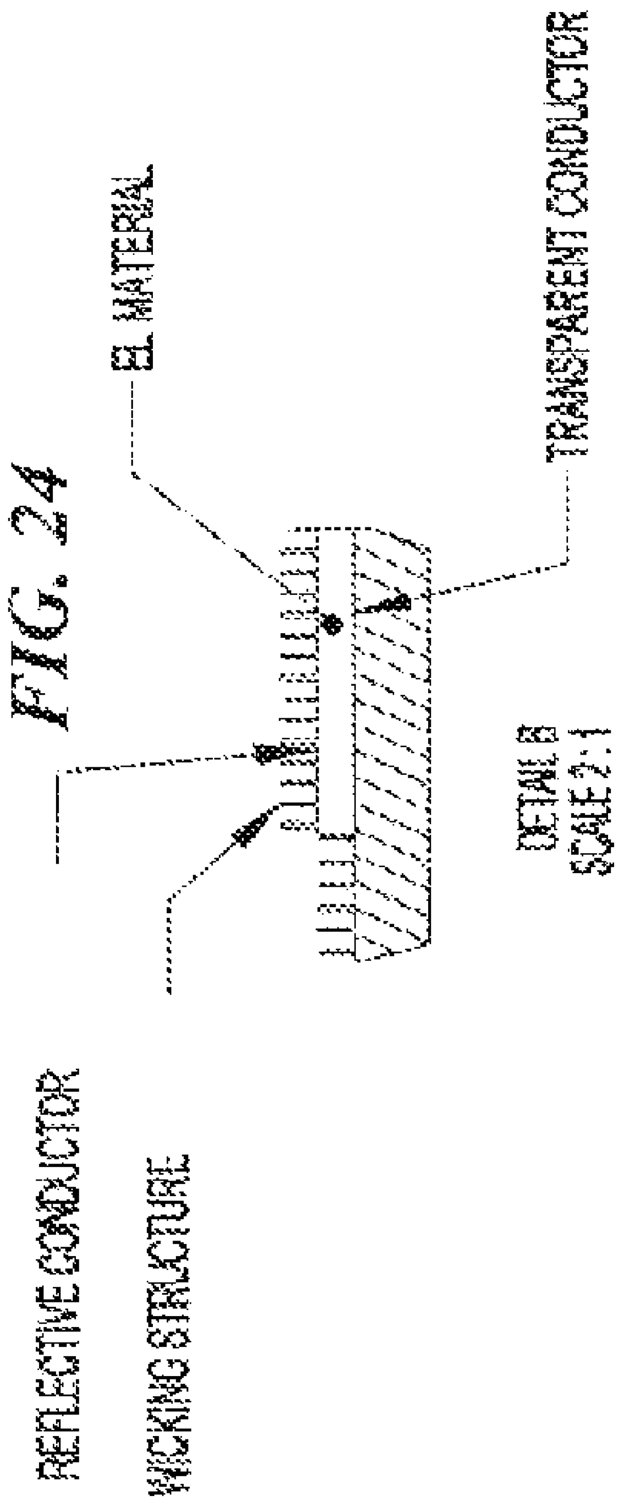
FIG. 16

FIG. 17

FIG. 18

FIG. 19

FIG. 20



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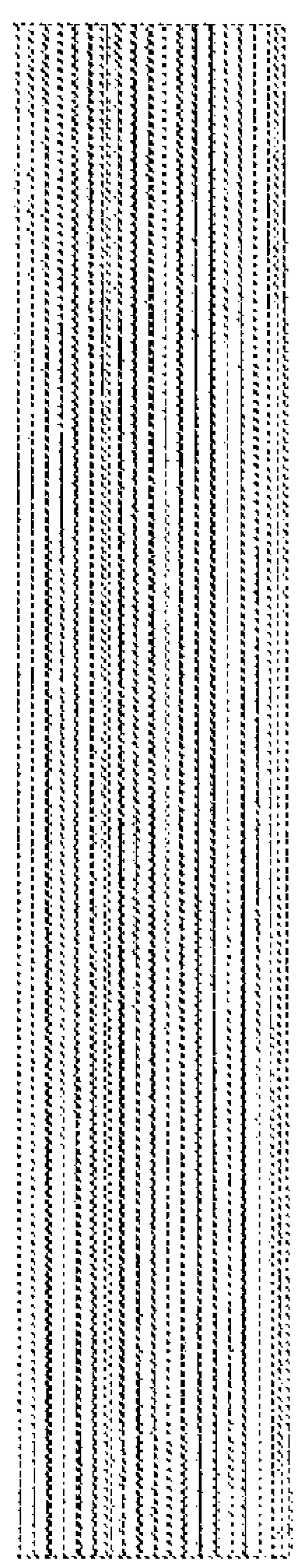


FIG. 21

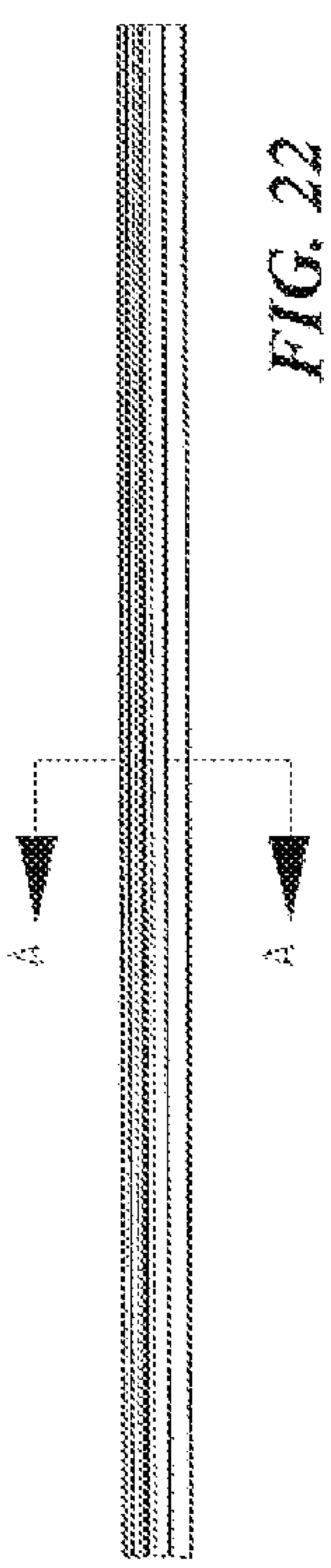


FIG. 22

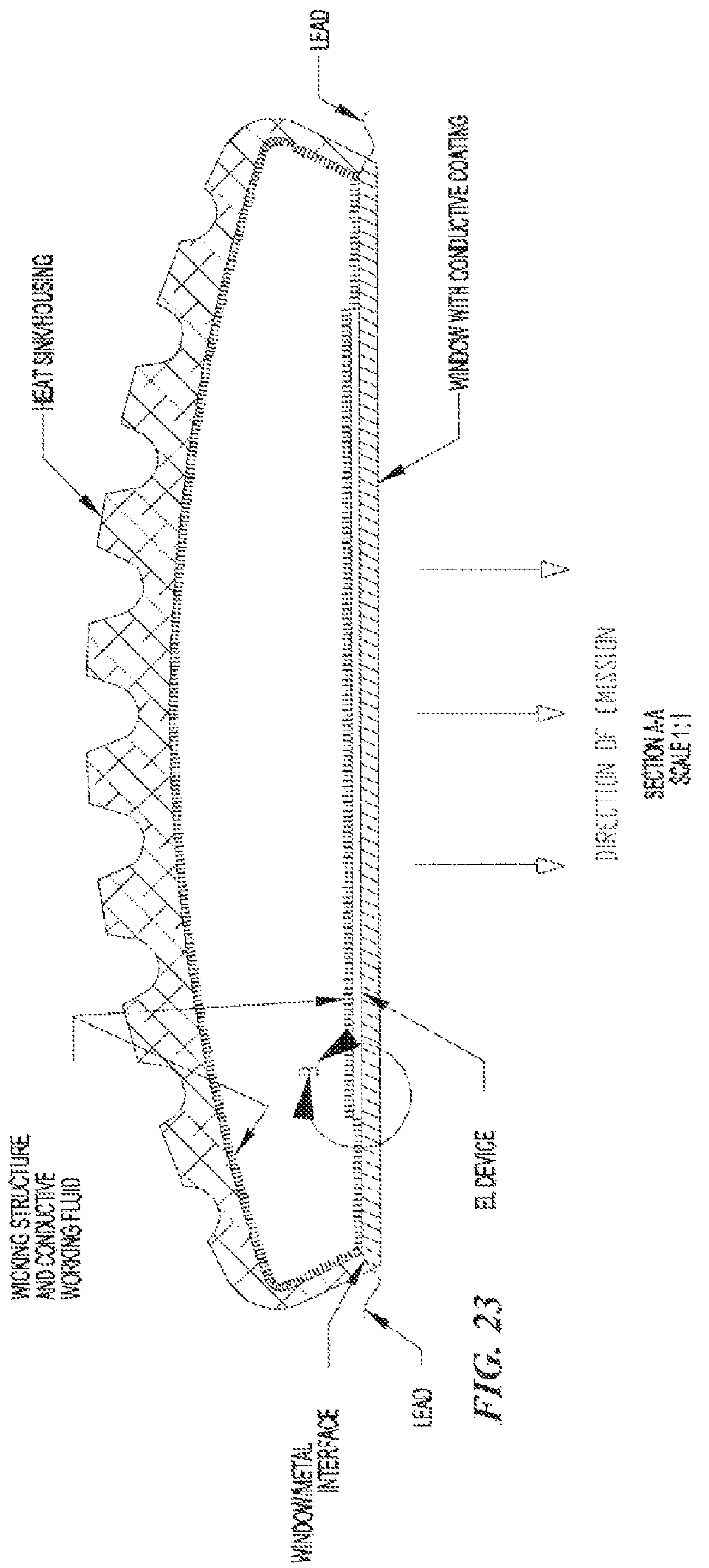


FIG. 23

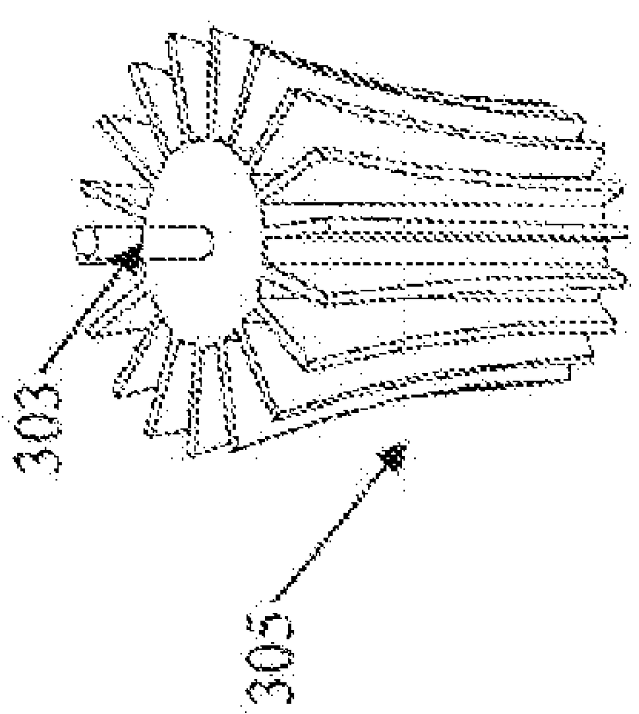


FIG. 26

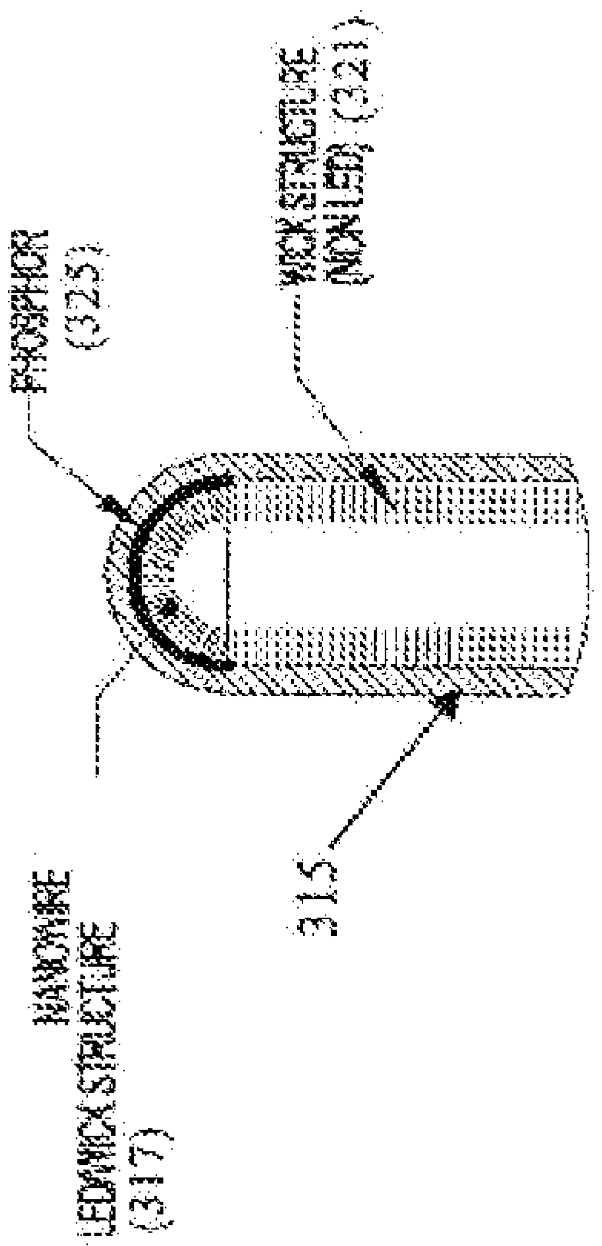


FIG. 27B

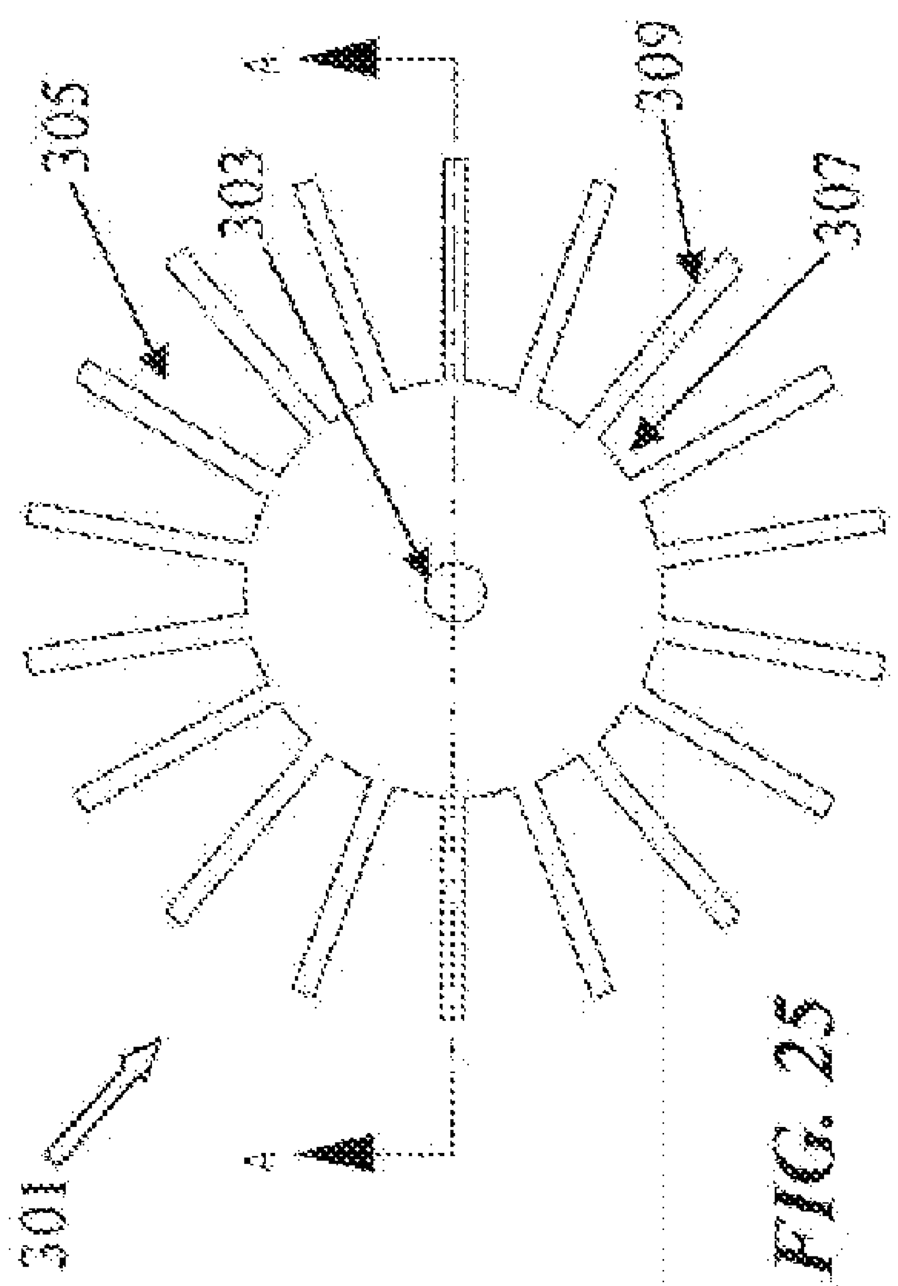


FIG. 25

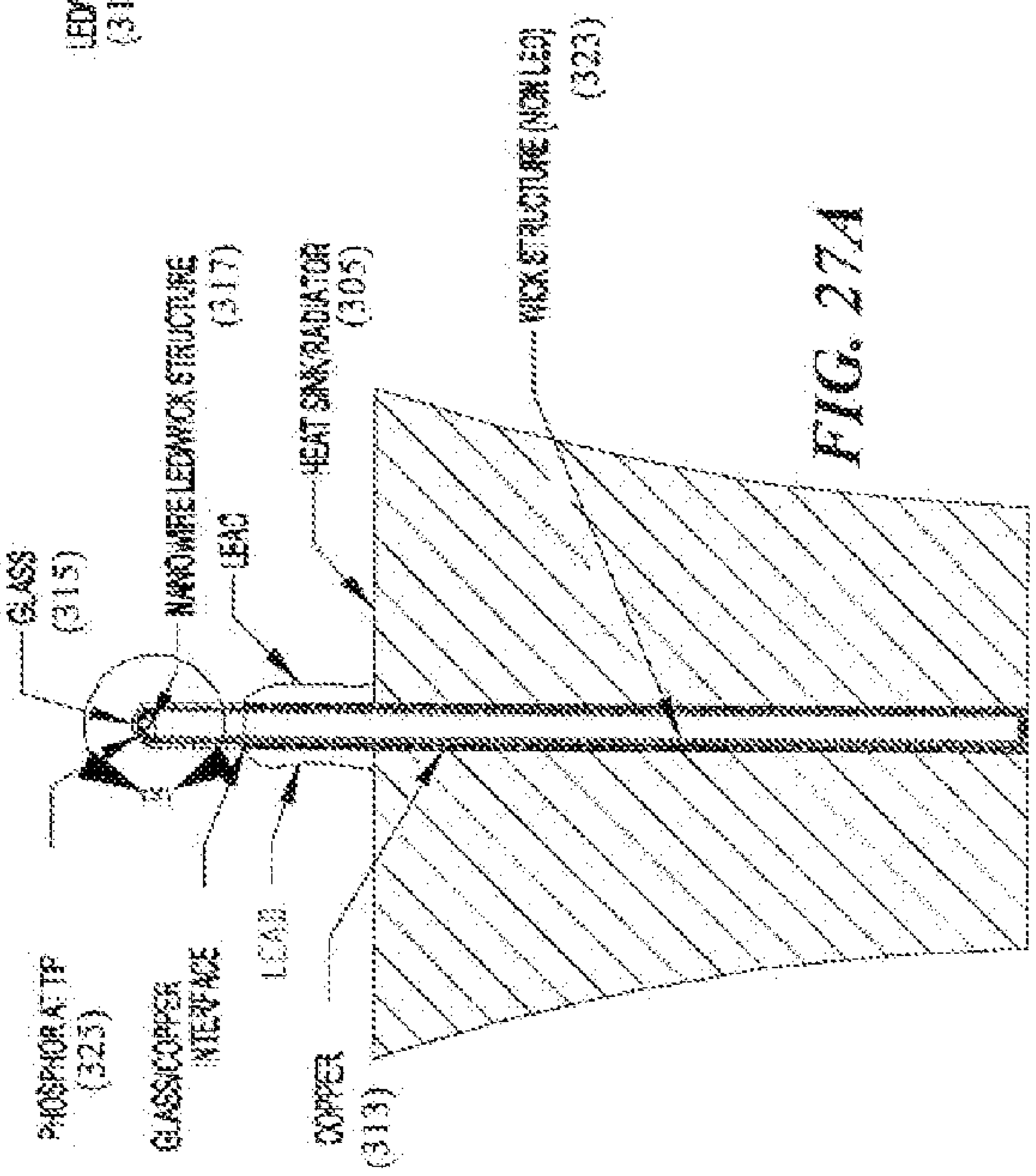


FIG. 27A

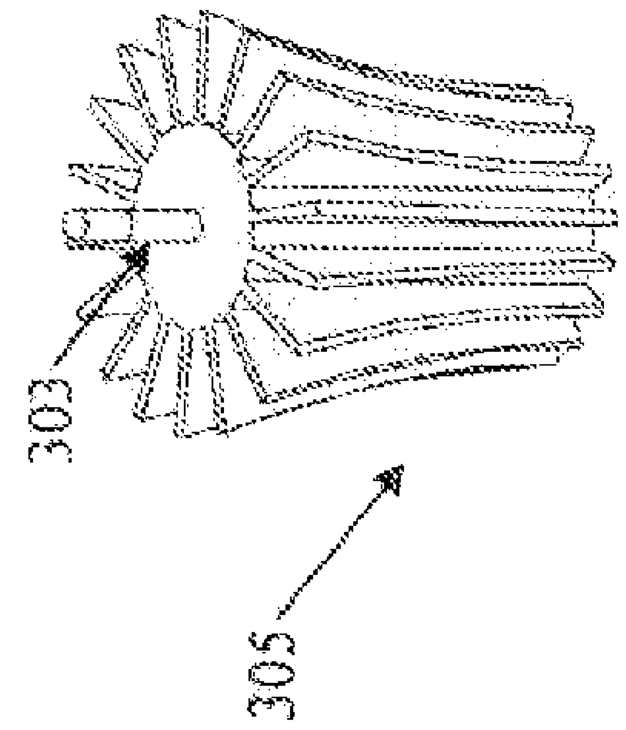


FIG. 29

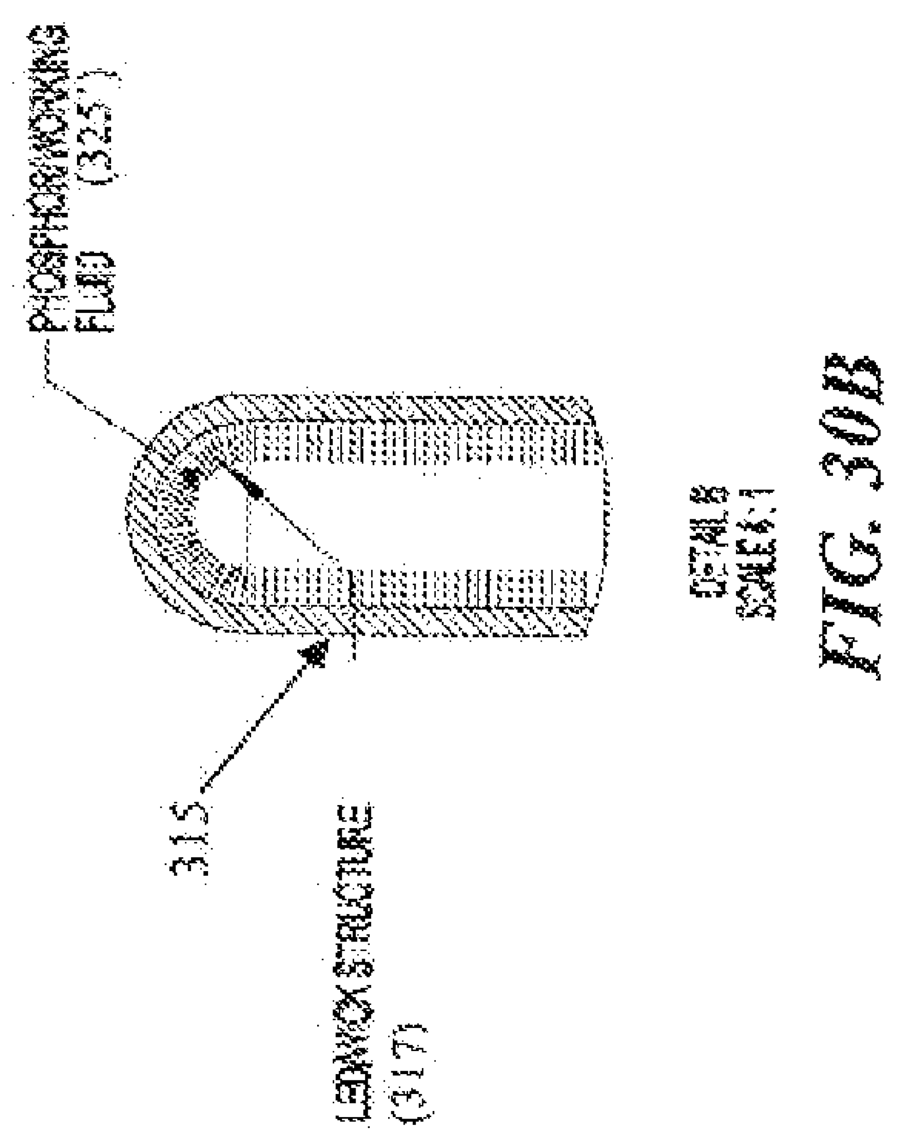


FIG. 30B

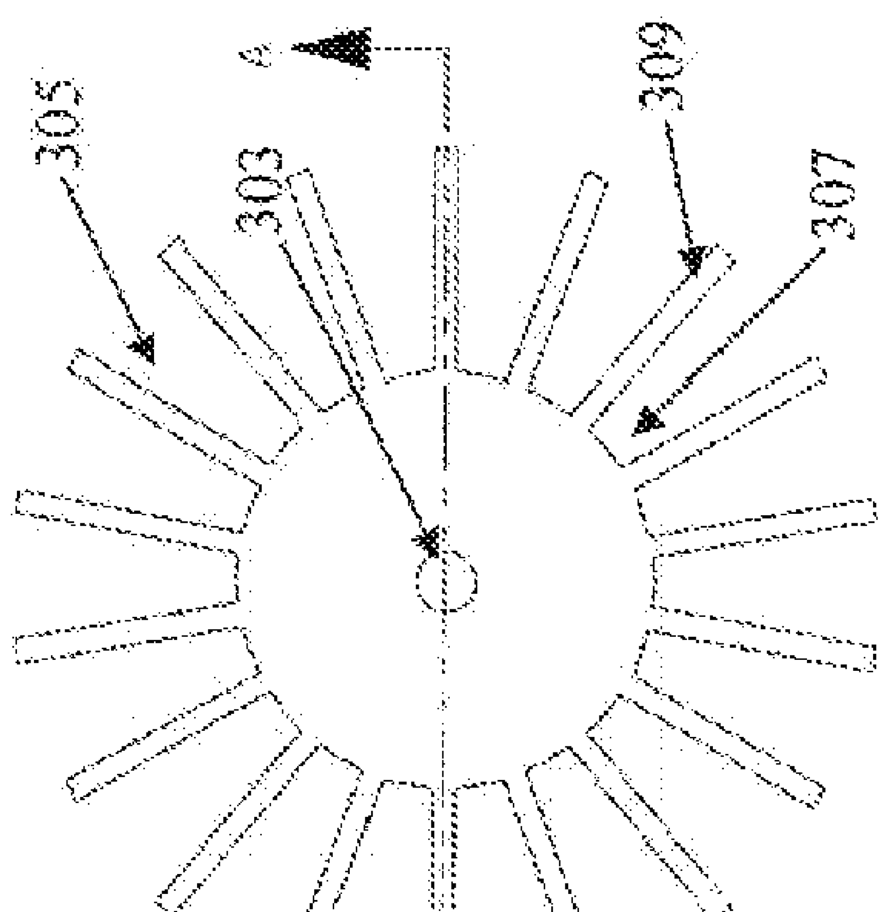


FIG. 28

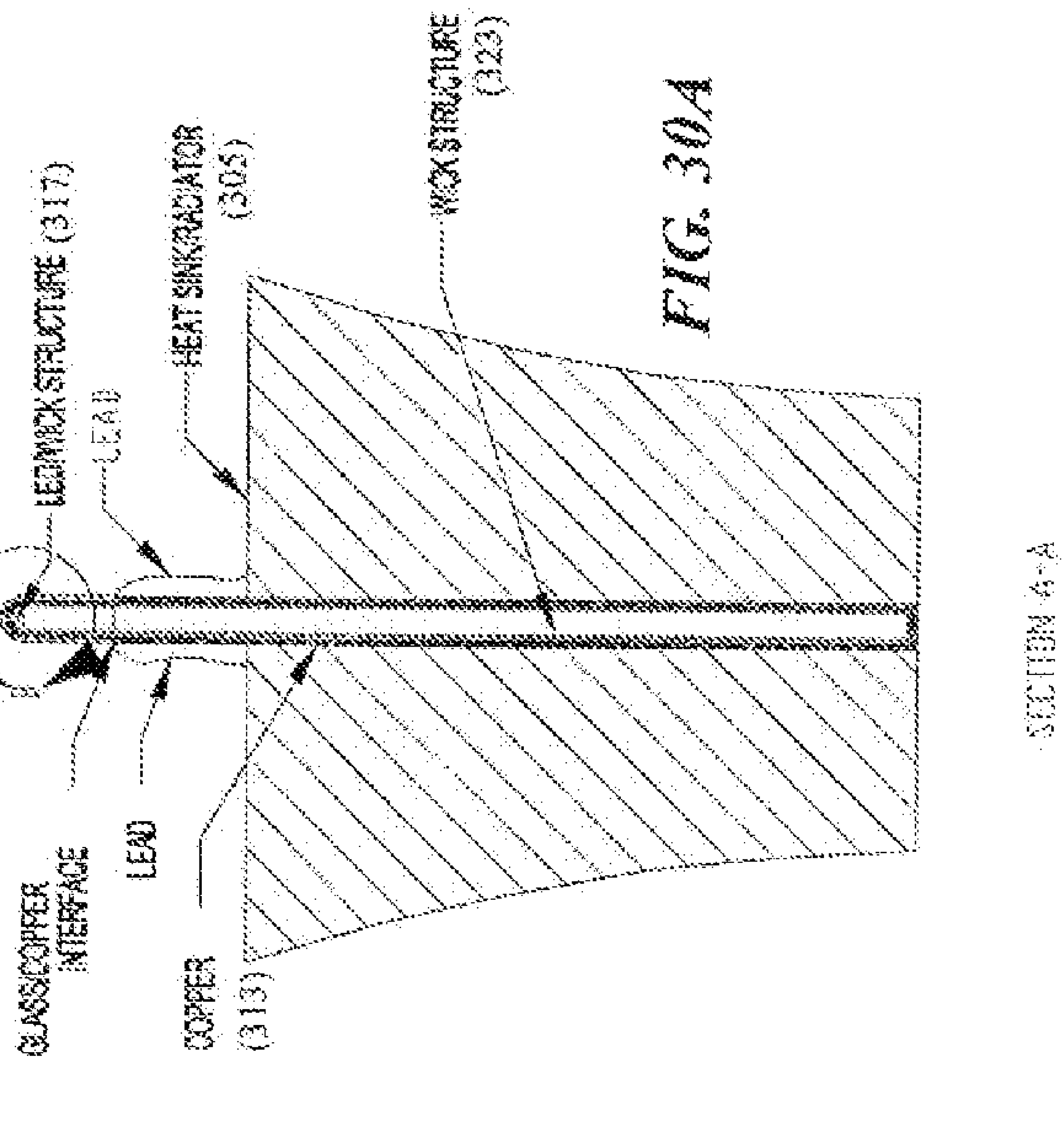
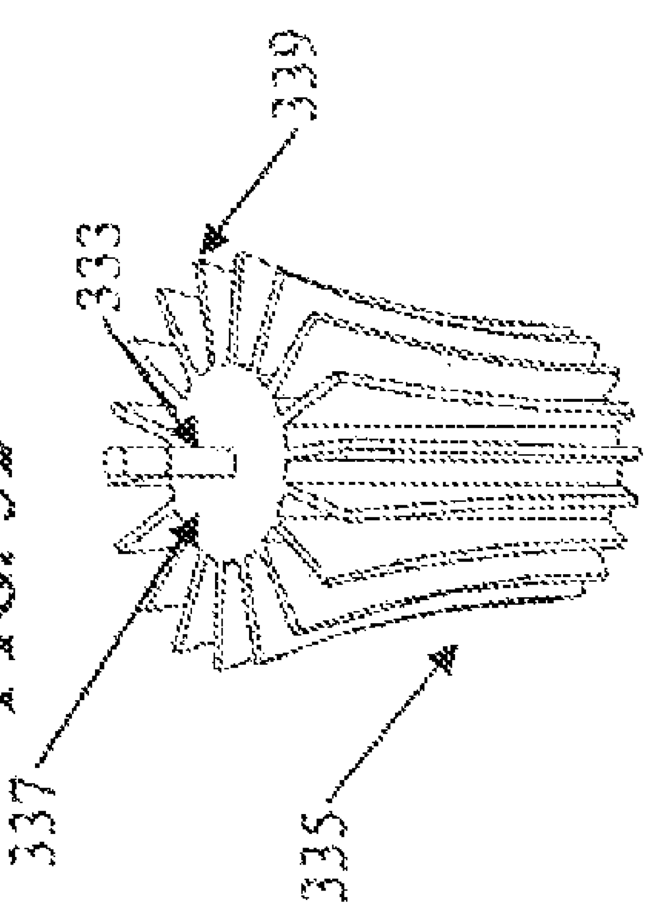


FIG. 30A

FIG. 32



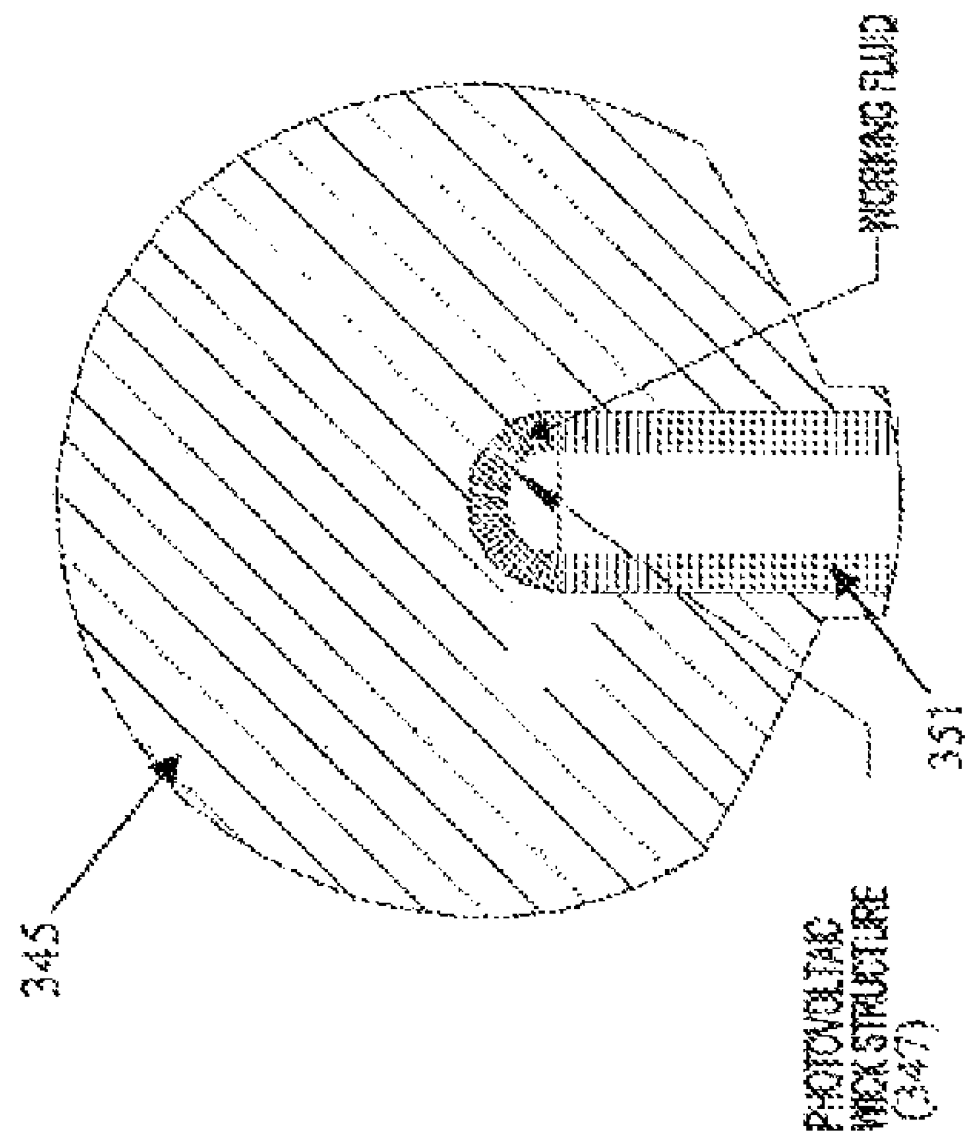


FIG. 33B

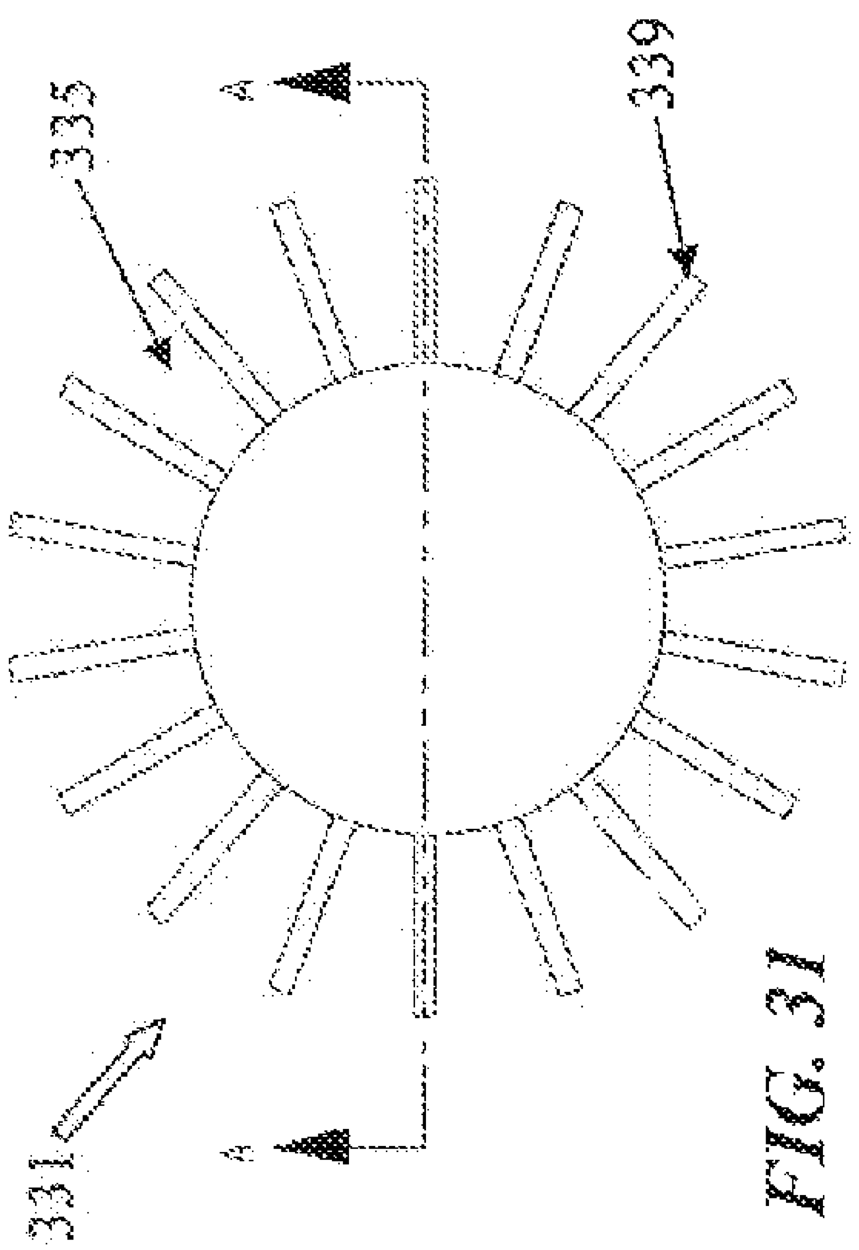


FIG. 31

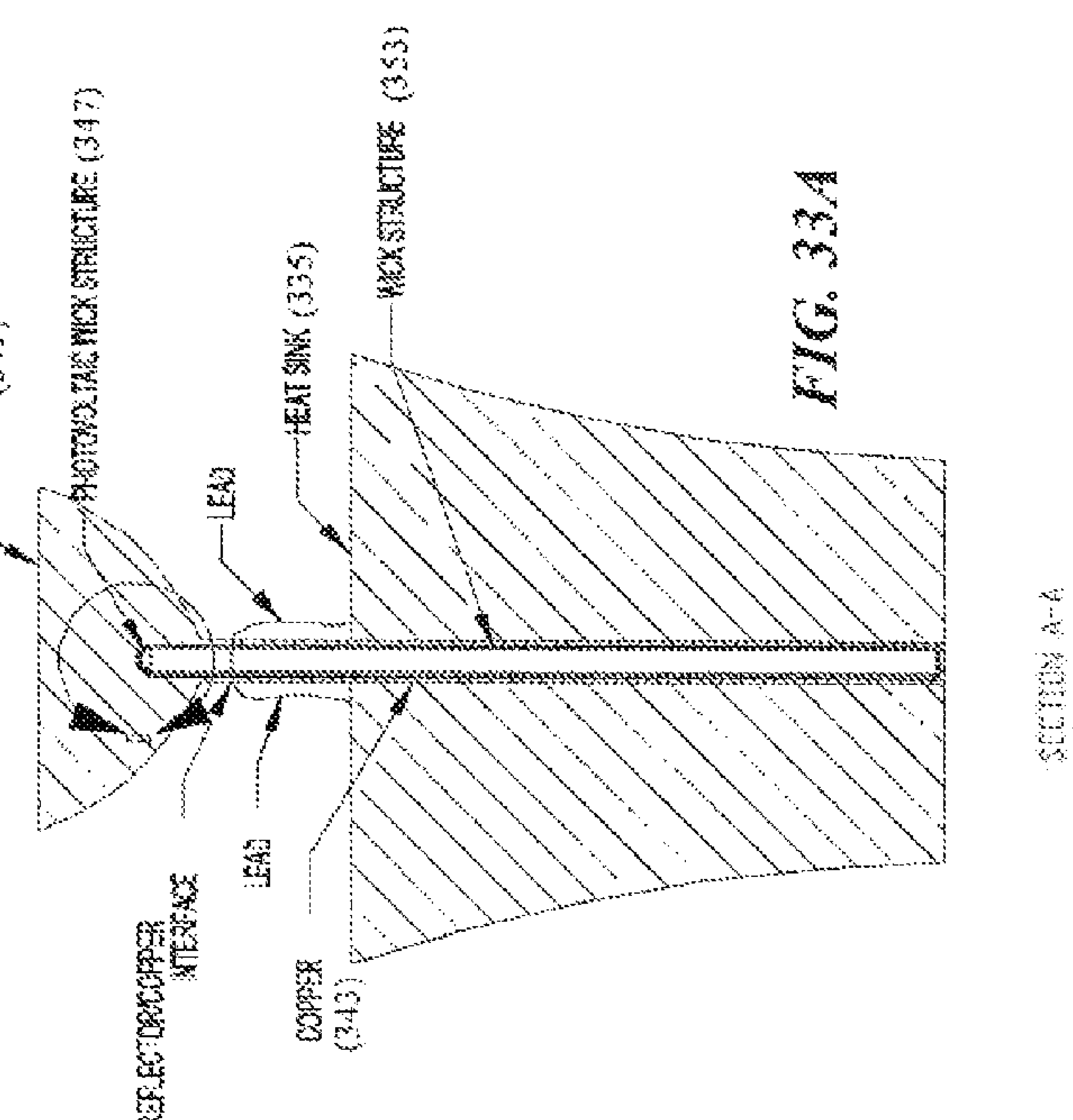


FIG. 33A

THERMAL CONDUCTIVITY AND PHASE TRANSITION HEAT TRANSFER MECHANISM INCLUDING OPTICAL ELEMENT TO BE COOLED BY HEAT TRANSFER OF THE MECHANISM

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 13/221,244, filed Aug. 30, 2011, entitled "THERMAL CONDUCTIVITY AND PHASE TRANSITION HEAT TRANSFER MECHANISM INCLUDING OPTICAL ELEMENT TO BE COOLED BY HEAT TRANSFER OF THE MECHANISM."

This application is related to U.S. patent application Ser. No. 13/221,083, filed Aug. 30, 2011, entitled "PHOSPHOR INCORPORATED IN A THERMAL CONDUCTIVITY AND PHASE TRANSITION HEAT TRANSFER MECHANISM."

This application is related to U.S. Utility application Ser. No. 13/221,050, filed Aug. 30, 2011, entitled "OPTICAL/ELECTRICAL TRANSDUCER USING SEMICONDUCTOR NANOWIRE WICKING STRUCTURE IN A THERMAL CONDUCTIVITY AND PHASE TRANSITION HEAT TRANSFER MECHANISM."

BACKGROUND

Many different types of active optical elements for emitting or responding to light used in optical/electrical transducers require effective dissipation of heat. Consider a semiconductor light emitter, such as a light emitting diode (LED) or laser diode, as a first example. To generate more light, the device is driven harder by a higher power drive current. However, the device then generates more heat.

The semiconductor may be damaged or break down if heated to or above a certain temperature. If the temperature gets too high, the device may burn out instantly. All semiconductor light emitters decline in efficiency of light generation as they are operated over time. However, even if the temperature is not high enough to burn out the device quickly, operating a semiconductor light emitter at relatively high temperatures (but below the burn-out temperature) for an extended period will cause the semiconductor light emitter to degrade more quickly than if operated at lower temperatures. Even when a device is running within its rated temperature, the hotter it gets, the less efficient it becomes. Conversely, the cooler the device operates, the more efficient it is.

Many available types of LEDs fail at ~150° C. LED performance data typically is based on junction temperature of 25° C. However, at more typical junction temperatures (~100° C.), operating performance is degraded by ~20% from the specified performance data.

As a solid state light emitter device such as a LED operates, the semiconductor generates heat. The heat must be effectively dissipated and/or the electrical drive power (and thus light output) must be kept low enough, to avoid breakdown or rapid performance degradation and/or to maintain operating efficiency. The package or enclosure of the semiconductor light emitter device typically includes a heat slug of a high thermal conductivity, which is thermally coupled to the actual semiconductor that generates the light.

In operation, the slug is thermally coupled to a cooling mechanism outside the device package, such as a heat pipe and/or a heat sink. External active cooling may also be provided.

To increase the intensity of the light generated, the semiconductor light, emitter may be driven with a higher intensity electrical current. Alternatively, an overall system or lighting device may include a number of semiconductor light emitters which together can produce a desired quantity of light output. With either approach, the increase in intensity of generated light increases the amount of heat that needs to be dissipated to avoid breakdown or rapid performance degradation and/or to maintain operating efficiency.

Also, many lighting technologies utilize phosphors that are susceptible to overheating. Again, consider a solid state lighting device, for a general lighting application, by way of an example. The solid state light sources typically produce light of specific limited spectral characteristics. To change or enhance the spectral characteristic of a solid state light source, for example, to obtain white light of a desired characteristic, one approach currently favored by LED (light emitting diode) manufacturers, utilizes a semiconductor emitter to pump phosphors within the device package (on or in close proximity to the actual semiconductor chip). Another approach uses one or more semiconductor emitters, but the phosphor materials are provided remotely (e.g. on or in association with a macro optical processing element such as a diffuser or reflector outside the semiconductor package). At least some opto-luminescent phosphors that produce desirable output light characteristics degrade quickly if heated, particularly if heated above a characteristic temperature limit of the phosphor material.

Hence, phosphor thermal degradation can be an issue of concern in many lighting systems. Thermal degradation of some types of phosphors may occur at temperatures as low as 85° C. Device performance may be degraded by 10-20% or more. The lifecycle of the phosphor may also be adversely affected by temperature.

At least some of the recently developed semiconductor nanophosphors and/or doped semiconductor nanophosphors may have an upper temperature limit somewhere in the range of 60-80° C. The light conversion output of these materials degrades quickly if the phosphor material is heated to or above the limit, particularly if the high temperature lasts for a protracted period.

Maintaining performance of the phosphors therefore creates a need for efficient dissipation of any heat produced during light generation. A current mitigation technique for phosphor thermal degradation is to maintain separation of the phosphor from the heat source and maximize unit area of phosphor to minimize flux density. However, the need for more lumens in an output using the phosphor requires larger phosphor unit area, and any limits placed on the flux density to reduce thermal impact on the phosphor constrains the overall device design.

The examples above relate to light generation devices or systems. However, similar heat dissipation issues may arise in devices or systems that convert light to other forms of energy such as electricity. For example light sensors or detectors and/or photovoltaic devices may degrade or breakdown if overheated, e.g. if subject to particularly intense input light of if subject to high light input over extended time periods. Even when a device is running within its rated temperature, the hotter it gets, the less efficient it becomes. Conversely, the cooler the device operates, the more efficient it is.

For these and other types of active optical elements for emitting or responding to light, there is a continuing need for ever more effective dissipation of heat. Improved heat dissipation may provide a longer operating life for the active optical element. Improved heat dissipation alight emitter to be driven harder to emit more light or all detector/second or photovoltaic to receive and process more intense light.

Many thermal strategies have been tried to dissipate heat from and cool active optical elements. Many systems or devices that incorporate active optical elements use a heat sink to receive and dissipate heat from the active optical element(s). A heat sink is a component or assembly that transfers generated heat to a lower temperature medium. Although the lower temperature medium may be a liquid, the lower temperature medium often is air.

A larger heat sink with more surface area dissipates more heat to the ambient atmosphere. However, there is often a tension or trade off between the size and effectiveness of the heat sink versus the commercially viable size of the device that must incorporate the sink. For example, if a LED based lamp must conform to the standard form factor of an A-lamp, that form factor limits the size of the heat sink. To improve thermal performance for some applications, an cooling element may be used, to dissipate heat from a heat sink or from another thermal element that receives heat from the active optical element(s). Examples of active cooling elements include fans, Peltier devices, membronic cooling elements and the like.

Other thermal strategies for equipment that use active optical elements have utilized heat pipes or other devices based on principles of a thermal conductivity and phase transition heat transfer mechanism. A heat pipe or the like may be used alone or in combination with a heat sink and/or an active cooling element.

A device such as a heat pipe relies on thermal conductivity and) transition between evaporation and condensation to transfer heat between two interfaces. Such a device includes a vapor chamber and working fluid within the chamber, typically at a pressure somewhat lower than atmospheric pressure. The working fluid, in its liquid state, contacts the hot interface where the device receives heat input. As the liquid absorbs the heat, it vaporizes. The vapor fills the otherwise empty volume of the chamber. Where the chamber wall is cool enough (the cold interface), the vapor releases heat to the wall of the chamber and condenses pack into a liquid. Thermal conductivity at the cold interface allows heat transfer away from the mechanism, e.g. to a heat sink or to ambient air. By gravity or a wicking structure, the liquid form of the fluid flows back to the hot interface. In operation, the working fluid goes through this evaporation, condensation and return flow to form a repeating thermal cycle that effectively transfers the heat from the hot interface to the cold interface. Devices like heat pipes can be more effective than passive elements like heat sinks, and they do not require power or mechanical parts as do active cooling elements. It is best to get the heat away from the active optical element as fast as possible, and the heat pipe improves heat transfer away from the active optical element, even where transferring the heat to other heat dissipation elements.

Although these prior technologies do address the thermal issues somewhat, there is still room for further improvement.

For example, passive cooling elements, active cooling elements and heat transfer mechanisms that rely on thermal conductivity and phase transition have been implemented outside of the devices that incorporate active optical elements. A light processing device may include one or more elements coupled to the actual active optical element to transfer heat to the external thermal processing device. In our LED example, heat passes through of the layers of the semiconductor, to the heat slug and then to the external thermal processing device(s). The need to transfer the heat through so many elements and the various interfaces between those elements reduces efficiency in cooling the thermally susceptible component(s) of the active optical element. Again referencing the LED example, the need to transfer the heat through so many elements reduces efficiency in cooling the LED chip, particularly cooling at the internal, the layer/point in the semiconductor chip where the light is actually generated.

It has been suggested that a heat pipe type mechanism could be incorporated at the package level with the LED (WO 2007/069119 (A1)). However, even in that device, a heat spreader and a light transmissive collimator encapsulate the actual LED chip and separate the chip from the working fluid. Heat from the LED chip structure is transferred through the heat spreader to the working fluid much like the prior examples that used art external heat pipe coupled to the heat slug of the LED package.

There is an increasing desire for higher, more efficient operation (light output or response to light input) in ever smaller packages. As outlined above, thermal capacity is a limiting technical factor. Thermal capacity may require control of heat at the device level (e.g. transducer package level and/or macro device level such as in a lamp or fixture). Also, for equipment utilizing phosphors, there is a continuing need for ever more effective dissipation of heat. Improved heat dissipation may provide a longer operating life for the apparatus or device using the phosphor(s), improved heat dissipation may allow a device to drive the phosphor harder, to emit more light, for a particular application.

Hence, it may be advantageous to reduce the distance and/or number elements and interfaces that the heat must pass through from the active optical element. As outlined above, thermal capacity may require control of heat at the phosphor level. Hence, it may be advantageous to improve technologies to more effectively dissipate heat from and/or around phosphor materials. Also, improvement in technologies to more effectively dissipate heat from active optical elements may help to meet increasing performance demands with respect to the various types of equipment that use the active optical elements.

BRIEF DESCRIPTION OF THE DRAWINGS

The drawing figures depict one or more implementations in accord with the present teachings, by way of example only, not by way of limitation. In the figures, like reference numerals refer to the same or similar elements.

FIG. **1**A is a cross-sectional view of a first example of a thermal conductivity and phase transition heat transfer mechanism that incorporates an active optical element, such as a multilayer optical/electrical transducer optical/electrical transducer.

FIG. **1**B is a cross-sectional view of an example of an optical/electrical transducer apparatus, in the form of a second thermal conductivity and phase transition heat transfer mechanism, in this example, as mechanism that incorporates an active optical element in the form of a semiconductor transducer utilizing semiconductor nanowires that also form at least a portion of the wicking structure of the thermal conductivity and phase transition heat transfer mechanism.

FIG. 1C is a cross-sectional view of an example of a third thermal conductivity and phase transition heat transfer mechanism that incorporates a phosphor within the thermal conductivity and phase transition heat transfer mechanism as the active optical element.

FIG. 2 is an enlarged detailed view of a portion of the semiconductor transducer in the apparatus of FIG. 1B, including a number of the semiconductor nanowires.

FIG. 3 is an enlarged detailed view of a portion of the thermally conductive part of the housing and associated part of the wicking structure, of a phase transition heat transfer mechanism of one of the examples of FIGS. 1A-1C, showing phosphor bearing nanowires.

FIG. 4 is an enlarged detailed view of a portion of the thermally conductive part of the housing and associated part of the wicking structure, of a phase transition heat transfer mechanism of one of the examples of FIGS. 1A-1C, showing metal nanowires.

FIG. 5 is a comparative diagram useful in explaining how reducing the size and increasing the number of thermal elements per unit area increases the surface area for heat transfer and reduces the thermal resistance, and thus shows the advantages of using nanowires or similarly sized elements in the wicking structure of a thermal conductivity and phase transition heat transfer mechanism.

FIGS. 6-8 are examples of devices similar to the device of FIG. 1A, where the optical/electrical transducer is a LED or photodiode (FIG. 6), electroluminescent devices (FIGS. 7A-7C), or an OLED (FIG. 8).

FIG. 9A is a cross-sectional view of an example of an optical/electrical transducer apparatus, where the semiconductor transducer, such as a LED or photodiode, utilizes semiconductor nanowires that also form a portion of the wicks structure, in a manner analogous to the example of FIGS. 1B and 2; and FIG. 9B is a cross-sectional view of an example of a lamp based on the principles of the example of FIG. 9A.

FIGS. 10A-10C are various views of an example of a light emitting device or light engine, having a source and a thermal conductivity and phase transition heat transfer mechanism that incorporates a phosphor within the thermal conductivity and phase transition heat transfer mechanism, in a manner analogous to the example of FIG. 1C.

FIG. 11 is a cross-sectional view of an example of a light fixture incorporating a light engine like that shown in FIG. 10B.

FIGS. 12-15 are various views of an example of as linear downlight utilizing an OLED in a thermal conductivity and phase transition heat transfer mechanism.

FIGS. 16-20 are various views of an example of street lamp utilizing a two-sided semiconductor light emitter and a two-chamber thermal conductivity and phase transition heat transfer mechanism.

FIGS. 21-24 are various views of an example of an electroluminescent device type linear downlight utilizing an electroluminescent emitter in a thermal conductivity and phase transition heat transfer mechanism.

FIGS. 25 and 26 are top and isometric views of a light emitting type optical/electrical transducer apparatus and heat sink as may be used in a fixture or lamplight bulb.

FIG. 27A is a cress-sectional view taken along line A-A of FIG. 25.

FIG. 27B is an enlarged detail view of a portion of the optical/electrical transducer apparatus and heat sink of FIG. 27A.

FIGS. 28 and 29 are top and isometric views of another light emitting type optical/electrical transducer apparatus and heat sink as may be used in a fixture or lamplight bulb.

FIG. 30A is a cross-sectional view taken along line A-A of FIG. 28.

FIG. 30B is an enlarged detail view of a portion of the optical/electrical transducer apparatus and heat sink of FIG. 30A, showing the addition of a phosphor layer.

FIGS. 31 and 32 are top and isometric views of a light receiving type optical/electrical transducer apparatus, a heat sink and a light concentrator, as may be used in for a sensor or photovoltaic apparatus.

FIG. 33A is a cross-sectional view taken along line A-A of FIG. 31.

FIG. 33B is an enlarged detail view of a portion of the optical/electrical transducer apparatus and heat sink of FIG. 33A.

DETAILED DESCRIPTION

In the following detailed description, numerous specific details are set forth by way of examples in order to provide a thorough understanding of the relevant teachings. However, it should be apparent to those skilled in the art that the present teachings may be practiced without such details. In other instances, well known methods, procedures, components, and/or circuitry have been described at a relatively high-level, without detail, in order to avoid unnecessarily obscuring aspects of the present teachings.

The various mechanisms, transducers, apparatuses and systems disclosed herein utilize thermal conductivity and phase transition heat transfer mechanisms that incorporate active optical elements. Examples of active optical elements include various phosphor materials for emitting light, various electrically driven light emitters and various devices that generate electrical current or an electrical signal in response to light. The thermal conductivity and phase transition between evaporation and condensation, of the thermal conductivity and phase transition heat transfer mechanism, cools the active optical element during operation. At least a portion of the active optical element is exposed to a working fluid within a vapor tight chamber of the heat transfer mechanism. The heat transfer mechanism includes a member that is at least partially optically transmissive to allow passage of light to or from the active optical element and to seal the chamber of the heat transfer mechanism with respect to vapor contained within the chamber.

An optical/electrical transducer apparatus is a device that converts between forms of optical and electrical energy, for example, from optical energy to an electrical signal or from electrical energy to an optical output. Examples of optical-to-electrical transducers include various sensors, photovoltaic devices and the like. Examples of electrical-to-optical transducers include various light emitters, although the emitted light may be in the visible spectrum or in other wavelength ranges.

The phase transition of the mechanism is closer to the actual active optical element and transfers heat away from the element more quickly. The element/mechanism would still often be used in combination with one or more other thermal transfer or heat dissipation elements, such as a heat sink and/or an active cooling element coupled to the cold interface of the mechanism.

Reference now is made in detail to the examples illustrated in the accompanying drawings and discussed below. FIG. 1A is a cross-sectional view of a somewhat stylized example of an optical/electrical transducer apparatus 1*a*, where the actual transducer is an active optical element **17***a* of or within a combined phase transition heat transfer mechanism.

An active optical element converts energy from one form or another by an electrical process and/or an excitation state change process, where at least one form of the energy is optical, e.g. light. Active optical elements include optically driven elements, such as optically pumped phosphors and/or electrical devices driven by light to produce electricity, as well as electrical devices and/or phosphors driven by electricity or electrical/electromagnetic fields to produce light. In the example, the active optical element **17***a* is a multi-layer solid state "transducer" in the form of a 'chip' or the like **19***a* for converting between light and electricity. Examples include semiconductor based light emitters, such as LEDs and OLEDS, as well electroluminescent devices. Examples also include light responsive devices, such as photovoltaic devices and photodiodes for sensor or detector type applications. Examples of mechanisms incorporating semiconductor devices that include semiconductor nanowires as the active optical elements and examples of mechanisms incorporating phosphor as the active optical elements are discussed later at a similarly high level with respect to FIGS. **1**B and **1**C. By contrast, passive optical elements process and even change the character of light, but by optical processing only, that is to say, without use of an electrical and/or excitation state change process. Examples of passive optical elements include windows, lenses, optical color filters, reflectors, gratings, diffusers, and the like.

The transducer apparatus **1***a* includes as housing **3***a*. The housing **3***a* has at least one section that is thermally conductive. In the example of FIG. **1**A, the major section **5***a* of the housing as is formed of as thermally conductive material. Examples of suitable materials include metals, such as copper and aluminum, although other thermally conductive materials, such as thermally conductive plastics and ceramics, may be used to form the housing section **5***a*. A portion of the housing section **5***a* will form as cold location **7***a*, for example, acting as or coupled to a heat sink (not separately shown).

The housing **3***a* has a member **9***a* that is at least partially optically transmissive. The member **9***a* may be transparent or translucent or exhibit other transmissive characteristics (e.g. non-white color filtering), depending on the optical requirements of the particular application of the transducer apparatus **1***a*. The material forming the member **9***a* may be any material of sufficient optical transmissivity and desired color characteristic for the particular application that is also able to withstand the expected operating temperatures of the transducer apparatus **1***a*. Examples of suitable materials for the member **9***a* include various forms of glass, ceramics and plastics. The material for the member **9***a* may or may not need to be heat resistant, depending on the operating temperature at the hot location **7***a* maintained by operation of the thermal conductivity and phase transition heat transfer mechanism. The optically transmissive member **9***a* is connected to the housing section **5***a* to form a seal for a vapor light chamber **11***a* enclosed by the thermally conductive housing lion **5***a* and the optically transmissive member **9***a*. The material of the member **9***a* is sufficiently transmissive to light, at least in the portion of the optical energy spectrum that is relevant to operations of the apparatus **1***a*, so as to allow passage of optical energy into and/or out of the apparatus **1***a*.

As noted the optically transmissive member is attached to the housing section **5***a* to form a seal for a vapor tight chamber **11***a*. For example, if the optically transmissive member is a glass or ceramic material and the housing section **5***a* is formed of a metal, the two elements may be joined by a glass fit process or by application of a suitable epoxy.

The exemplary apparatus **1***a* also includes a working fluid within the chamber **11***a*. The pressure within the chamber **11***a*, typically a pressure somewhat lower than atmospheric pressure, configures the working fluid to absorb heat during operation of the apparatus, to vaporize at a relatively hot location **13***a* as it absorbs heat, to transfer heat to and condense at the relatively cold location **7***a*, and to return as a liquid to the relatively hot location. A variety of different fluids may be used as the working fluid and the pressure is determined based on the fluid type and the amount of heat that the fluid is expected to transfer.

The working fluid, in its liquid state, contacts the hot interface at the location **13***a* where the apparatus receives or produces heat. In the example, heat it absorbed from surfaces of the multi-layer solid state transducer **19***a* of the active optical element **17***a*. As the liquid absorbs the heat, it vaporizes. The vapor fills the otherwise empty volume of the chamber **11***a*. Where the chamber all is cool enough (the cold interface at location **7***a*), the vapor releases heat to the wall of the chamber **11***a* and condenses back into a liquid. The drawing shows a central arrow from the hot location **13***a* toward the cold location **7***a*. This arrow generally represents the flow of heat in the vapor state of the working fluid from the hot location **13***a* where the working, fluid vaporizes toward the cold location **7***a* where the working fluid transfers heat for output via the thermally conductive housing section **5***a* and condenses back to the liquid form. The liquid form of the fluid flows back to the hot interface at location **13***a*. The drawing shows arrows generally along the outer wall(s) of the housing from the relatively cold location **7***a* back to the relatively hot location **13***a*. The arrows generally represent the flow of the condensed working fluid from the relatively cold location **7***a* back to the relatively hot location **13***a* where the fluid again vaporizes as it absorbs heat. In operation, the working fluid goes through this evaporation, condensation and return flow to form a repeating thermal cycle that effectively transfers the heat from the hot interface at location **13***a* to the cold interface at location **7***a*.

The apparatus **1***a* thus is configured as a thermal conductivity and phase transition heat transfer mechanism, similar to many mechanisms which are sometimes referred to as "heat pipes." The thermal conductivity of the housing section **5***a* and the phase transition cycle through evaporation and condensation transfer heat from the hot location **13***a* to the cold location **7***a*. Thermal conductivity at the cold interface allows heat transfer away from the mechanism, e.g. to a heat sink or to ambient air. Active cooling may also be provided. The configuration of the mechanism together with the degree of cooling determines the internal operating temperature. For example, the mechanism and a heat sink ma support a maximum internal operating temperature around 50° C. Addition of active cooling or refrigeration at the cold interface may enable operation at a much lower internal temperature, such as 0° C.

The exemplary apparatus **1***a* also includes a wicking structure **15***a* mounted within the chamber **11***a* to facilitate flow of the condensed liquid of the working fluid from the cold location **7***a* to the hot location **13***a* of the mechanism **1***a*. Capillary action or "wicking" relies on inter-molecular threes between a liquid and the surface(s) of a material around the liquid to cause movement of the liquid along or through the material. This action can overcome other forces on the liquid, such as gravity, to promote a desired movement of the liquid. In the thermal conductivity and phase transition heat transfer mechanism, the wicking structure **15***a* promotes movement of the condensed liquid back from the cold location **7***a* to the hot location **13***a*.

The wicking structure **15***a* may take many forms, such as sintered metal, phosphor, glass or ceramic powder; woven copper; surface grooves, mesh arrangements or small closely spaced wires extending inward from the surfaces of the housing forming the walls of the chamber **11***a*; as well as nano-scale wire structures extending inward from the chamber surface(s); and various combinations of these forms. The spacing between elements of the wicking structure **15***a* is sufficiently small to cause inter-molecular forces on the liquid form of the working fluid to cause the liquid to flow toward the region where the fluid vaporizes, that is to say, the hot location **13***a* in the apparatus **1***a*. This wicking or capillary action enables the liquid form of the working fluid to flow hack to the hot location **13***a* regardless of the orientation of (and thus the impact of gravity on fluid in) the heat transfer mechanism.

The apparatus **1***a* includes an active, optical element **17***a*. In this case, the active optical element is an optical/electrical transducer, in the form of a multi-layer device or chip as shown at **19***a*. The transducer **17***a* converts between optical and electrical energy. The present teachings apply to transducers **17***a* for emitting light in response to an electrical drive signal or for receiving and responding to light to produce an electrical signal. In the apparatus **1***a* light enters the apparatus through the optically transmissive member **9***a*, for an optical-to-electrical conversion application to reach the transducer **17***a*. For an electrical-to-optical conversion application, light produced by operation of the transducer **17***a* emerges from the apparatus **1***a* through the optically transmissive member **9***a*.

If the apparatus **1***a* is cylindrical, then when viewed from either end, the apparatus **1***a* would appear circular. The member **9***a* could be circular or have other shapes, even in a cylindrical implementation of the apparatus **1***a*. Those skilled in the art will appreciate that the lateral shapes of the mechanism as a whole and of the optically transmissive member may take other geometric forms, such as oval, rectangular or square, just to name a few examples.

The orientation in the drawing, in which light enters the apparatus **1***a* or is emitted from the apparatus **1***a* to the left in directions about a somewhat horizontal central axis, is shown only for purposes of illustration. Those skilled in the art will appreciate that the apparatus may be used in any other orientation that is desirable or suitable far any particular application of the transducer apparatus. Some implementations may utilize more than one optically transmissive member, to facilitate receipt or emission of light in additional directions. Although not shown, passive optical processing elements, such as diffusers, reflectors, lens and the like, may be coupled to the optically transmissive member to process light directed into the transducer apparatus **1***a* or to process light emitted from the transducer apparatus **1***a*.

The examples discussed herein with regard to FIG. **1**A relate to transducer type active antics elements **17***a* that are formed of one or more layers **19***a*, such as layers form an electroluminescent device or a semiconductor crevice. The transducer **17***a* is configured to emit light through the optically transmissive member **9***a*, and/or to be driven by light received via the optically transmissive member **9***a*. At least a portion of a surface of the multilayer chip or the like **19** is exposed to the working fluid in the chamber **11***a* of the mechanism and is accessible for direct transfer of heat to the working fluid at the hot location **15***a*, to facilitate efficient cooling of the element **17***a* by the thermal conductivity and phase transition heat transfer of mechanism **1**.

FIG. **1**B is a cross-sectional view of a somewhat stylized example of an optical/electrical transducer apparatus **1***b*, where the actual transducer is an active optical element **17***b* of or within a combined phase transition heat transfer mechanism. In this second example, the active optical element **17***b* is a semiconductor "transducer" for converting between light and electricity that, at least, in part, uses semiconductor nanowires **19***b* to produce or respond to light. The nanowires **19***b* are also part of as wicking structure **15***b*.

The transducer apparatus **1***b* includes a housing **3***b*. The housing **3***b* has at least one section that is thermally conductive. In the example of FIG. **1**B, the major section **5***b* of the housing **3***b* is formed of a thermally conductive material. Examples of suitable materials include metals, such as copper and aluminum, although other thermally conductive materials, such as thermally conductive plastics and ceramics, may be used to form the housing section **5***b*. A portion of the housing section **5***b* will form a cold location **7***b*, for example, acting as or coupled to a heat sign not separately shown).

The housing **3***b* has a member **9***b* that is at least partially optically transmissive. The member **9***b* may be transparent or translucent or exhibit other transmissive characteristics (e.g. non-white color filtering), depending on the optical requirements of the particular application of the transducer apparatus **1***b*. The material forming the member **9***b* may be any material of sufficient optical transmissivity and desired color characteristic for the particular application that is also able to withstand the expected operating temperatures of the transducer apparatus **1***b*. Examples of suitable materials for the member **9***b* include various forms of glass, ceramics and plastics. The material for the member **9***b* may or may not need to be heat resistant, depending on the operating temperature at the hot location **7***b* maintained by operation of the thermal conductivity and phase transition heat transfer mechanism. The optically transmissive member **9***b* is connected to the housing section **5***b* to form a seal for a vapor tight chamber **11***b* enclosed by the thermally conductive housing section **5***b* and the optically transmissive member **9***b*. The material of the member **9***b* is sufficiently transmissive to light, at least in the portion of the optical energy spectrum that is relevant to operations of the apparatus **1***b*, so as to allow passage of optical energy into and/or out of the apparatus **1***b*.

As noted, the optically transmissive member **9***b* is attached to the housing section **5***b* to form as seal for a vapor tight chamber **11***b*. For example, if the optically transmissive member **9***b* is a glass or ceramic material and the housing section **5***b* is formed of a metal, the two elements may be joined by a glass frit process or by application of a suitable epoxy.

The exemplary apparatus **1***b* also includes a working fluid within the chamber **11***b*. The pressure within the chamber **11***b*, typically a pressure somewhat lower than atmospheric pressure, configures the working fluid to absorb heat during operation of the apparatus, to vaporize at a relatively hot location **13***b* as it absorbs heat, to transfer heat to and condense at the relatively cold location **7***b*, and to return as a liquid to the relatively hot location. A variety of different fluids may be used as the working fluid, and the pressure is determined based on the fluid type and the amount of heat that the fluid is expected to transfer.

The working fluid, in its liquid state, contacts the hot interface at the location **13***b* where the apparatus receives or produces heat. In the example, heat is absorbed from surfaces of the semiconductor nanowires **19***b* of the transducer element **17***b*. As the liquid absorbs the heat, it vaporizes. The vapor fills the otherwise empty volume of the chamber **11***b*. Where the chamber wall is cool enough (tile cold interface at location **7***b*), the vapor releases heat to the wall of the chamber **11***b* and condenses back into as liquid. The drawing shows a central arrow from the hot location **13***b* toward the cold location **7***b*. This arrow generally represents the flow of heat in the vapor state of the working fluid from the hot location **13***b* where the working fluid vaporizes toward the cold location **7***b* where the working fluid transfers heat for output via the thermally conductive housing section **5***b* and condenses back to the liquid form. The liquid form of the fluid flows back to the hot interface at location **13***b*. The drawing, shows arrows generally along the outer wall(s) of the housing from the relatively cold location **7***b* back to the relatively hot location **13***b*. The arrows generally represent the flow of the condensed working fluid from the relatively cold location **7***b* hack to the relatively hot location **13***b* where the fluid again vaporizes as it absorbs heat. In operation, the working fluid goes through this evaporation, condensation and return flow to form a repeating thermal cycle that effectively transfers the heat from the hot interface at location **13***b* to the cold interface at location **7***b*.

The apparatus **1***b* thus is configured as a thermal conductivity and phase transition heat transfer mechanism, similar to many mechanisms which are sometimes referred to as "heat pipes." The thermal conductivity of the housing section **5***b* and the phase transition cycle through evaporation and condensation transfer heat from the hot location **15***b* to the cold location **7***b*. Thermal conductivity at the cold interface allows heat transfer away from the mechanism, e.g. to a heat sink or to ambient air. Active cooling may also be provided. The configuration of the mechanism together with the degree of cooling determines the internal operating temperature. For example, the mechanism and a heat sink may support a maximum internal operating temperature around 50° C. Addition of active cooling or refrigeration at the cold interface may enable operation at a much lower internal temperature, such as 0° C.

Like the example of FIG. **1**A, the exemplary apparatus **1***b* also includes a wicking structure **15***b* mounted within the chamber **11***b* to facilitate flow of the condensed liquid of the working fluid from the cold location **7***b* to the hot location **13***b* of the mechanism **1***b*. In the thermal conductivity and phase transition heat transfer mechanism, the wicking structure **15***b* promotes movement of the condensed liquid back from the cold location **7***b* to the hot location **13***b*.

The wicking structure **15***b* may take many forms, such as sintered metal, phosphor, glass or ceramic powder; woven copper; surface grooves, mesh arrangements or small closely spaced wires extending inward from the surfaces of the housing forming the walls of the chamber **11***b*; as well as nano-scale structures extending inward from the chamber surface(s); and various combinations of these forms. The spacing between elements of the wicking structure **15***b* is sufficiently small to cause inter-molecular forces on the liquid form of the working fluid to cause the liquid to flaw toward region where the fluid vaporizes, that is to say, the hot location in the apparatus **1***b*. This wicking or capillary action enables the liquid form of the working fluid to flow hack to the hot location **13***b* regardless of the orientation of (and thus the impact of gravity on fluid in) the heat transfer mechanism.

The apparatus **1***b* includes an active optical element **17***b*. In this the active optical element is an optical/electrical transducer. The transducer **7***b* converts between optical and electrical energy. The present teachings apply to transducers **17***b* for emitting light in response to an electrical drive signal for receiving and responding to light to produce an electrical signal. In the apparatus **1***b*, light enters the apparatus through the optically transmissive member **9***b*, for an optical-to-electrical conversion application to reach the transducer **17***b*. For an electrical-to-optical conversion application, light produced by operation of the transducer **17***b* emerges from the apparatus **1***b* through the optically transmissive member **9***b*.

If the apparatus **1***b* is cylindrical, then when viewed from either end, the apparatus) **1***b* would appear circular. The member **9***b* could be circular or have other shapes, even in a cylindrical implementation of the apparatus **1***b*. Those skilled in the art will appreciate that the lateral shapes of the mechanism as a whole and of the optically transmissive member may take other geometric forms, such as oval, rectangular or square, just to name a few examples.

The orientation in the drawing, in which light enters the apparatus **1***b* or is emitted from the apparatus **1***b* to the left in directions about a somewhat horizontal central axis, is shown only for purposes of illustration. Those skilled in the art will appreciate that the apparatus may be used in any other orientation that is desirable or any particular application of the transducer apparatus. Some implementations may utilize more than one optically transmissive member, to facilitate receipt or emission of light in additional directions. Although not shown, passive optical processing elements, such as diffusers, reflectors lens and the like, may be coupled to optically transmissive member to process light directed into the transducer apparatus **1***b* or to process light emitted from the transducer apparatus **1***b*.

The examples discussed herein relate to transducers **17***b* that are formed at least in part by semiconductor nanowires **19**, and in an apparatus like that of FIG. **1**B, the nanowires also serve as part of the wicking structure for purposes of promoting the liquid flow in the phase transition cycle of the heat transfer mechanism.

Hence, in the example of FIG. **1**B, the wicking, structure **15***b* includes at least two different portions **19***b* and **21***b*. The portion of the wicking structure **19***b* is formed of the semiconductor nanowires that also form at least part of the actual optical/electrical transducer **17***b* within the chamber **11***b*. The semiconductor transducer **17***b* that includes the semiconductor nanowires **19***b* of the wicking structure **15***b* is configured to emit light through the optically transmissive member **9**, and/or the semiconductor transducer **17***b* that includes the semiconductor nanowires **19***b* of the wicking structure is configured to be driven by light received via the optically transmissive member **9***b*.

FIG. **1**C is a cross-sectional view of an example of a thermal conductivity and phase transition heat transfer mechanism **1***c* that incorporates a phosphor material, as the active optical element. In this example, the source of energy to pump or excite the phosphor is not included inside the mechanism and is omitted for case of illustration anti discussion. Later drawings show examples with the source outside the mechanism and as well as examples with the source inside the mechanism.

The mechanism **1***c* includes a housing **3***c*. The housing **3***c* has at least one section that is thermally conductive. In the example of FIG. **1**C, the major section **5***c* of the housing **3***c* is formed of a thermally conductive material. Examples of suitable materials include metals, such as copper and aluminum, although other thermally conductive material materials, such as thermally conductive plastics and ceramics, may be used form manufacture the housing section **5***c*.

The housing **3***c* has at least one member **9***c* that is at least partially optically transmissive. In this example, the mechanism **1***c* includes two members **9***c* and **10***c*, each of which is at least partially optically transmissive. Each optically transmissive member **9***c* or **10***c* may be transparent or translucent or exhibit other transmissive characteristics (e.g. non-white color filtering), depending on the optical requirements of the particular application of the mechanism **1***c*. In an example like that of FIG. **1**C, in which the mechanism does not incorporate the source, at least one of the optically transmissive members **9***c*, **10***c* would allow entry of optical energy from an external source, whereas one or both of the optically transmissive members **9**, **10***c* would allow emission of light as an output. The optically transmissive members **9***c* and **10***c* appear flat in cross-section, although they could have other shapes, e.g. convex or concave, if a particular shape would promote light input or light output for a particular application.

If the apparatus **1***c* is cylindrical, then when viewed from either end, the apparatus **1***c* would appear circular. Either member **9***c* or member **10***c* could be circular or have other shapes, even in a cylindrical implementation of the apparatus **1***c*. Those skilled in the art will appreciate that the lateral shapes of the mechanism as a whole and of the optically transmissive member(s) may take other geometric forms, such as oval, rectangular or square, just to name a few examples.

The material forming each optically transmissive member **9***c* or **10***c* may be any material of sufficient optical transmissivity that is also able to withstand the expected operating temperatures of the mechanism **1***c*. Examples of suitable materials for the members **9***c*, **10***c* include various forms of glass ceramics and plastics. The material, of the optically transmissive members **9***c*, **10***c* may or may not need to be heat resistant, depending on the temperature at the location of each member during operation. Each optically transmissive member **9***c* or **10***c* is connected to the housing section **5***c* to form a seal for a vapor tight chamber **11***c* enclosed by the thermally conductive housing section **5***c* and the optically transmissive members **9***c*, **10***c*. The material of the member **9***c* or **10***c* is sufficiently transmissive to light, at least in the portion of the optical energy spectrum that is relevant to operations of the mechanism **1***c*, so as to allow passage of optical energy into and/or out of the apparatus **1***c*.

As noted, the optically transmissive members **9***c*, **10***c* are attached to the housing section **5***c* to form a seal for a vapor tight chamber **11***c*. For example, if the optically transmissive members **9***c*, **10***c* are formed of a glass or ceramic material and the housing section **5***c* is thrilled of a metal, the different elements may be joined by a glass frit process or by application of a suitable epoxy.

The mechanism or device **1***c* also includes an opto-luminescent phosphor **17***c* contained within the chamber for emitting light, when excited by optical pumping energy. The phosphor **17***c* is the active optical element of the mechanism or device **1***c*. In some of the later examples, other active optical elements, in addition to the phosphor, are provided within the chamber **11***c* of the apparatus **1***c*. As discussed more later, light emitted by the excited phosphor **17***c* is output from the mechanism via one or both of the optically transmissive members **9***c*, **10***c*. The heat transfer function of the mechanism **1***c* mitigates thermal impact on the phosphor **17***c*.

A portion of the housing section **5***c* will form a cold location **7***c* within the chamber **11**, for example, acting as or coupled to a heat sink (not separately shown). In the example of FIG. **1**C, a cold location **7***c* is formed near an end portion of the thermally conductive housing section **5***c* and the second optically transmissive member **10***c*. Of course, any heat sink coupled to the mechanism at or near the cold location would not optically block passage of light to/from the optically transmissive member **10***c* in this example.

The exemplary apparatus **1***c* also includes a working fluid within the chamber **11***c*. The pressure within the chamber **11***c*, typically a pressure somewhat lower than atmospheric pressure, configures the working fluid to absorb heat during operation of the apparatus, to vaporize at a relatively hot location **13***c* as it absorbs heat, to transfer heat to and condense at the relatively cold location **7***c*, and to return as a liquid to the relatively hot location. A variety of different fluids may be used as the working fluid, and the pressure is determined based on the fluid type and the amount of heat that the fluid is expected to transfer.

The working fluid, in its liquid state, contacts the hot interface at the location **13***c* where the apparatus receives or produces heat. In the example, the working fluid directly contacts at least some surface area(s) of the phosphor layer **17***c* at or near the hot location **13***c*. At those surface areas, the working fluid absorbs at least some heat from the phosphor, be it heat generated by excitation of the phosphor or heat the phosphor may receive from the external excitation source.

As the liquid absorbs the heat, it vaporizes. The vapor fills the otherwise empty volume of the chamber **11***c*. Where the chamber wall is cool enough (the cold interface at location **7***c*), the vapor releases heat to the wall of the chamber **11***c* and condenses back into a liquid. The drawing shows a central arrow from the hot location **13***c* toward the cold location **7***c*. This arrow generally represents the flow of heat in the vapor from the hot location **13***c* where the working fluid vaporizes toward the cold location **7***c* where the working fluid transfers heat for output via the thermally conductive housing section **5***c* and condenses back to the liquid form. The liquid form of the fluid flows hack to the hot interface at location **13***c*. The drawing shows arrows generally along the outer wall(s) of the housing from the relatively cold location **7***c* back to the relatively hot location **13***c*. The arrows generally represent the flow of the condensed working fluid from the relatively cold location **7***c* back to the relatively hot location **13***c* where the fluid again vaporizes as it absorbs heat. In operation, the working fluid goes through this evaporation, condensation and return flow to form a repeating thermal cycle that effectively transfers the heat from the hot interface at location **13***c* to the cold interface at location **7***c*.

The device **1***c* in the example thus is configured as a thermal conductivity and phase transition heat transfer mechanism, similar to many mechanisms which are sometimes referred to as "heat pipes". The thermal conductivity of the housing section **5***c* and the phase transition cycle through evaporation and condensation transfer heat from the hot location **13***c* to the cold location **7***c*. Thermal conductivity at the cold interface allows heat transfer away from the mechanism, e.g. to a heat sink or to ambient air. Active cooling may also be provided. The configuration of the mechanism together with the degree of cooling determine the internal operating temperature, e.g. at the hot location **13***c*. For example, the mechanism and a heat sink may support a maximum internal operating temperature around 50° C. Addition of active cooling or refrigeration at the cold interface may enable operation at a much lower internal temperature, such as 0° C.

Although some thermal conductivity and phase transition heat transfer mechanisms do not include a wicking structure, the exemplary mechanism **1***c* also includes a wicking structure **15***c* mounted within the chamber **11***c* to facilitate the flow of condensed liquid of the working fluid from the cold location **7***c* to the hot location **13***c* of the mechanism **1***c*. In the thermal conductivity and phase transition heat transfer mechanism **1***c*, the wicking structure **15***c* promotes movement of the condensed liquid back from the cold location **7***c* to the hot location **13***c*.

The wicking structure **150** may take many forms, such as sintered metal, phosphor, glass or ceramic powder; woven copper; surface grooves, mesh arrangements or small closely spaced wires extending inward from the surfaces of the housing forming the walls of the chamber **11***c*; as well as nano-scale wire structures extending inward from the chamber surface(s); and various combinations of these forms. The spacing between elements of the wicking structure **15***c* is sufficiently small to cause inter-molecular forces on the liquid form of the working fluid to cause the liquid to flow toward the region where the fluid, vaporizes, that is to say, the hot location **13***c* in the mechanism **1***c*. This wicking or capillary action enables the liquid form of the working fluid to flow back to the hot location regardless of the orientation of (and thus the impact of gravity on fluid in the heat transfer mechanism **1***c*.

As noted briefly above, the mechanism **1***c* includes an active optical element **17***c* that is to be cooled by the thermo-dynamic operation of the combined phase transition heat transfer mechanism. In this case, the active optical element that is to be cooled is a phosphor that emits light when pumped, specifically an opto-luminescent phosphor contained within the chamber **11***c*. The opto-luminescent phosphor **17***c* is contained within the chamber **11***c* formed by the housing **3***c* of the thermal conductivity and phase transition heat transfer mechanism **1***c*, in such a manner that at least a portion of a surface of the phosphor **17***c* is directly contacted by the working fluid through gaps or vias in the wick **23***c* formed on the phosphor layer **17**, at the location **13***c* where the fluid evaporates as it absorbs heat. The phosphor may be provided in the chamber in a variety of different ways and other examples will be discussed below with regard to the later drawing figures. In this example, the phosphor takes the form of a layer at **17***c* formed on an inner surface of the chamber **11***c*, specifically a layer on the inward facing surface of the optically transmissive member **9***c*.

The phosphor **17***c* will be subject to heating during operation, due to excitation and/or due to heat passing through the housing **5***c* into the chamber **11***c* from the external source, e.g. if the source is adjacent to the member **9***c* and the phosphor **17***c*. The working fluid is directly in contact with at least a portion of the opto-luminescent phosphor **17***c*.

The phosphor within the layer at **17***c* is of a type for emitting light when excited by optical energy. Some of the light produced by the excited phosphor passes through one or both of the optically transmissive members **9***c*, **10***c*. For example, if optical excitation energy is supplied to the phosphor in layer **17***c* via the first optically transmissive member **9***c*, some phosphor emission may pass back through the optically transmissive member **9***c*. However, much of the phosphor emission passes through the chamber **11***c* and the optically transmissive member **10***c*. Reflective materials may be provided on the walls of the chamber **11***c* to reduce loss of light passing through the chamber **11***c*, for example, by use of a reflective wick along some sections of the chamber walks). The light for exciting the phosphor may also be applied through the optically transmissive member **10***c*, instead of or in addition to excitation energy supplied through the optically transmissive member **9***c*.

An opto-luminescent “phosphor,” as used in this and several other examples, may be any of a variety of optically excited luminescent materials. Electroluminescent phosphor materials are discussed with regard to other examples. Terms relating to opto-luminescent phosphor are intended to encompass a broad range of materials excited by optical energy of a first or ‘excitation’ band that re-generate light in a different second or ‘emission’ band that is at least somewhat different from the excitation band. Examples of phosphors that may be used in various applications discussed herein include traditional phosphors, such as rare-earth phosphors, as well as semiconductor nanophosphors sometimes referred to as quantum dots or Q-dots, and doped semiconductor nanophosphors. Those skilled in the art will also appreciate that phosphors of similar types and/or of different types, emitting light of different spectral characteristics, may be used in combination.

The orientation in the drawing, in which light enters the mechanism **1***c* and is emitted from the mechanism **1***c* in one or both lateral directions about a somewhat horizontal central axis, is shown only for purposes of illustration. Those skilled in the art will appreciate that the apparatus may be used in any other orientation that is desirable or suitable fix, any particular application of the mechanism **1***c*. Some implementations may utilize additional optically transmissive members, to facilitate receipt or emission of light in additional directions. Although not shown, passive optical processing elements, such as diffusers, reflectors, lens and the like, may be coupled to each optically transmissive member to process light directed into the mechanism **1***c* or to process light emitted from the mechanism **1***b*.

As noted earlier, the wicking structure **15***c* may take many forms. The wicking structure may be substantially the same on all of the relevant inner surfaces of the housing **5***c*, or there may be somewhat different wicks at different locations within the chamber **11***c*. For example, there may be two different types of wicks, one type wick **21***c* formed on the thermally conductive section **5***c* and possibly the optically transmissive member **10***c* and another type wick **23***c* formed on the phosphor layer **17***c*. For example, the wick **23***c* may be transmissive and/or formed of the phosphor material as grooves or wire extensions of the phosphor material. The wick **21***c* may be at least somewhat reflective although the portion of the wick on the member **10***c* may be transmissive.

As noted above, the thermal conductivity and phase transition heat transfer mechanisms may use a variety of different wicks as the wicking structures; and in some examples at least, one mechanism may include two or more different kinds of wicks. Although other types of wicks may be used, many of the specific examples discussed herein utilize nano-scale structures or nanowires as one or more of the types of wicks in particular exemplary mechanisms. The example of FIG. 1B uses a semiconductor wick **19***b* as or as part of the transducer **17***b*. Instead of or in addition to the layer **17***c*, the example ic of FIG. **1**C could utilize phosphor hearing nanowires as some or all of the wicking structure. Phosphor bearing nanowire wicks also could be used in the examples of FIGS. **1**A and **1**B, in addition to the active optical elements **17***a* and **17***b*. In each of the three examples of FIGS. **1A-1C**, it may also be useful to have at least some of the wicking structure formed of a reflective material, such as a reflective mesh or reflective metallic nanowires. To further appreciate the structure of such exemplary nanowire wicks, in may be helpful to discuss them in somewhat more detail with respect to FIGS. **2-4**.

FIG. **2** shows an example of a section of the optical/electrical transducer **17***b*, utilizing the semiconductor nanowire portion **19***b* of the wicking structure. As discussed here, applicable semiconductor light emitters essentially include any of a wide range light emitting or generating devices formed from organic or inorganic semiconductor materials. Similarly, the present discussion encompasses any of a wide range of sensors, photovoltaics or other transducers for producing an electrical signal in response to optical energy that may be formed from organic or inorganic semiconductor materials.

The active optical element, in this case the optical/electrical transducer **17***b*, includes a conductive base **25**. The base may be formed of an appropriate conductive material. For an arrangement like that of FIG. **1**B, where the transducer **17***b* is adjacent to the optically transmissive member **9***b*, the conductive base **25** may also be optically transmissive. For example, the conductive base **25** can be formed of Indium Tin Oxide (ITO), other similar transparent conductive oxides, transparent conducting polymers, or layers consisting of transparent carbon nanotubes. The transparent conductive base **25** could form the optically transmissive member **9***b* of the apparatus housing **3**, but in the example of FIGS. **1**B and **2**, the conductive base **25** is a separate element or layer on or adjacent to the optically transmissive member **9** of the apparatus housing **3***b*. If ITO or another similar transparent conductive oxide is used, for example, the transparent conductive base **25** could take the form of a layer formed on a portion of the inner surface of the optically transmissive member **9***b*. Although not separately shown, an electrical connection will be provided to the base **25**, to provide one of the current path couplings to the semiconductor device of the actual transducer **17***b*.

The transducer also includes nanowires **19***b* grown to extend out from the conductive base **25**. Nanowires are wire-like structures having nano-scale cross-sectional dimensions. Although the cross-section of as nanowire may not be circular, it is often easiest to consider the lateral dimension of the nanowire to be a diameter. An individual nanowire **27** therefore may have an outer diameter measured in nanometers, e.g. in a range of approximately 1-500 nanometers. "nanowire" is meant to refer to any continuous wire or filament of indefinite length having an average effective diameter of nanometer (nm) dimensions. The "nanowire" term is therefore intended to refer to nanostructures of indefinite length, which may have a generally circular cross-sectional configuration or a non-circular cross-section (e.g. nanobelts having a generally rectangular cross-section).

Each individual semiconductor nanowire **27** in the example includes an inner nanowire **29** as a core and an outer nanowire **31**. The inner and outer nanowires are doped with different materials so as to be of different semiconductor types. In the example, the inner nanowire **29** is an N type semiconductor, and the outer nanowire **31** is a P type semiconductor, although obviously, the types could be reversed. As a result of the semiconductor growth and doping processes, there is semiconductor junction or intrinsic region **33** formed between the two semiconductor type nanowires **29**, **31**. In the example, the material forming the intrinsic region and the P type semiconductor also extends over the inner surface(s) of the conductive base **25** between the N type inner nanowires **29**. Those skilled in the art will recognize that the doping may be applied so as to essentially reverse the semiconductor types, e.g. So that the inner core nanowire **29** is as P type semiconductor and the outer nanowire **31** is an N type semiconductor.

Although not shown, reflectors may be provided at the distal ends (away from the base **25**) of the semiconductor nanowires **27** to direct more of the light produced by the nanowire diodes back through the base **25** and the light transmissive member **9***b*.

FIG. **2** also illustrates some of the working fluid **35** of the phase transition cycle of the heat transfer mechanism. The working fluid **35** directly contacts the outer surface(s) of at least the nanowires **27** of the semiconductor transducer, so that the fluid **35** may efficiently absorb heat from the transducer **17***b* during operation of the transducer. As noted, the conductive base **25** provides one of the electrical connections to the semiconductor nanowires **27**, in this example, to the N type semiconductor inner nanowires **29**. Although other types of electrical connections to the outer nanowires **31** could be provided, in the example of FIG. **2**, the electrical connection to the P type semiconductor outer nanowires **31** is provided via the working fluid **35**. To that end, the example uses a fluid **35** that is electrically conductive. Although not shown, the apparatus of FIG. **1**B would include a conductive connection to the working fluid, for example, via a conductor connected to a metal forming the section **5***b* of the housing **3***b*.

The semiconductor type optical/electrical transducer can provide conversion between optical and electrical energy or can provide conversion between electrical and optical energy. For an optical-to-electrical energy conversion, such as in a sensor or photovoltaic device, light energy applied to the semiconductor device produces to voltage across the P-N junction at the intrinsic region **33** of each nanowire **27**, which allows a current to flow through as circuit via the conductive base **25** and the working fluid **35**. For an electrical-to-optical energy conversion, the inner and outer nanowires together form a light emitting diode. A voltage is applied to produce a drive current through the diode, via the conductive base **25** and the working fluid **35**. Application of a voltage at or above the diode turn-on threshold, across the P-N junction at the intrinsic region **33**, causes each of each of the nanowires **27** to produce light.

The discussion of FIG. **2** focused on the semiconductor structure of the transducer **17***b* within the chamber **11***b* and the transducer operation. However, the nanowires **27** also form part of the wicking structure **15** of the combined phase transition and heat transfer mechanism. The spacing between the nanowires **27** is sufficiently small so as to facilitate capillary action on the working fluid **35**, so that the nanowires **27** also function as portion **19** of the wicking structure **15***b* in the apparatus **1***b* of FIG. **1**B. Although the entire wicking structure **15***b* could be formed of semiconductor nanowires like the nanowires **27**, the wicking structure **15***b* also includes a somewhat different portion **21***b*. The other example **1***a* of FIG. **1**A also includes a wicking structure **15***a*, which may be formed of one, two or more types of nanowire wicks on the surface of the transducer **19***a* and/or the walls of the thermally conductive housing section **5***a*, some of which may bear phosphor and some of which may be reflective. As noted earlier, an example similar to that of FIG. **1**C may use phosphor hearing nanowires as part of the wicking structure and/or may use a reflective wick or mesh or nanowires.

FIGS. **3** and **4** show two specific examples of arrangements that may be used as some or the entire a wicking structure in the exemplary mechanisms of FIGS. **1**A-**1**C. The example of FIG. **3** uses a wicking arrangement **22***a* formed of nanowires **37**. However, in the example of FIG. **3**, the nanowires **37** are formed of an optically luminescent material such as a phosphor or phosphor bearing medium.

The phosphor or medium may be grown as nanowires **37** extending inward into the interior of the chamber from the inner surface of the section **5** of the housing. By way of an example, particles of suitable phosphor(s) may be dispersed in a polymer matrix, and the phosphor-polymer matrix is grown in the form of nanowires. Examples of suitable polymers include epoxies and silicon. A barrier layer of a few nanometers up to around a micron may be provided on the surface of the phosphor nanowires **37**, so long at the barrier layer does not substantially impede flow of light to or from the phosphor or flow of heat from the excited phosphor to the fluid. The phosphor converts some of the optical energy within the chamber from energy in one wavelength range (the excitation band of the phosphor) to another somewhat different wavelength range. There may or may not be some overlap of the excitation and emission spectra of the phosphor.

In an optical-to-electrical transducer application, the phosphor may convert some energy in a wavelength range that the semiconductor transducer can not process to a wavelength range that the semiconductor transducer can process or can at least process more efficiently. Converted light produced by the phosphor nanowires will eventually reach the semiconductor transducer within the chamber, and can then be processed more effectively by the transducer. Hence, the phosphor conversion may improve sensitivity of the transducer apparatus **1***a* or **1***b*.

In an electrical-to-optical transducer application, the phosphor may convert some energy from the semiconductor light emitting transducer from as less desirable wavelength range (e.g. near or outside the visible spectrum) to a more desirable wavelength range (e.g. to fill-in a gap in the spectral characteristic of light produced by the emitter), to improve efficiency of the transducer apparatus **1***a* or **1***b* and/or to improve the quality of the light output. In the electrical-to-light type optical transducer application, the phosphor receives light emitted by the semiconductor transducer **17***a* or **17***b* that has not yet emerged from the apparatus **1***a* or **1***b* via the optically transmissive member **9***a* or **1***b*. If in sections of the chamber not at or near the member, the phosphor recycles such light and retransmits it within the chamber for eventual passage through the transducer and the optically transmissive member. Phosphor bearing nanowires **37** may be used in place of or in addition to the phosphor layer **17***c* in the example of FIG. **1**C.

Instead of a phosphor wicking structure as in FIG. **3**, the example of FIG. **4** uses a metal nanowire wicking structure **22***b*. In the example of FIG. **4**, metallic nanowires **39** of sufficient size and closeness to function as the wicking structure are grown so as to extend inward from the inner surface of the thermally conductive section **5** of the housing. In addition to supporting the capillary wicking function, the nanowires **39** may help support current flow to or from the conductive working fluid, if the fluid is conductive. The nanowires **39** may also be reflective to reflect light within the chamber hack to the transducer and/or the optically transmissive member, so as to improve re-circulation of light within the chamber and thereby improve overall optical performance of the apparatus, in any of the examples of FIGS. **1**A-**1**C.

Although referred to as a phosphor, each nanowire may include one or more phosphors of different types where the mix of phosphors is chosen to promote a particular application of the apparatus or mechanism. Another multi-phosphor approach might use a phosphor of one type in nanowires in one region of the chamber and a phosphor of another type in a different region of the chamber.

In both the examples of FIGS. **3** and **4**, the working fluid may be conductive. Where an optical-luminescent function is desirable, the working fluid **35***a* may also be or include a phosphor or the like. If phosphor particles are contained in the fluid **35***a*, the particle surfaces may be exposed to the fluid or the particles may be encapsulated in a barrier layer of a few nanometers up to around a micron, so long at the barrier layer does not substantially impede flow of light to or from the phosphor or flow of heat from the excited phosphor to the fluid medium. The phosphor in the working fluid **35***a* may enhance certain aspects of performance in a manner similar to that discussed above relative to the phosphor of the nanowires **37** in the example of FIG. **3**.

The examples of FIGS. **3** and **4** relate to different nanowire arrangements for one or more portions of the wicking structure. In both cases, the size and spacing of the nanowires would be such as to provide, a capillary flow of the liquid form of the working fluid. The working fluid **35** or **35***a* would directly contact the outer surface(s) of the respective nanowires.

The use of nanowires in the wicking structure, particularly at the hot and cold locations, also improves heat transfer. In general, smaller more numerous heat transfer elements at these locations present increased surface area for heat transfer to/from the working fluid and therefore represent decreased thermal resistance. FIG. **5** is a comparative diagram useful in explaining how reducing the size and increasing the number of thermal elements per unit area of the housing wall increases total surface area for heat transfer and reduces the thermal resistance, both of which help to improve the rate of thermal transfer to/from the working fluid contacting the thermal transfer elements, in this case contacting the nanowires. It is believed that this comparison helps demonstrate and explain advantages of using nanowires or similarly sized elements in the wicking structure of the combined phase transition heat transfer mechanism of an optical/electrical transducer apparatus.

For discussion purposes, the square under each identifier (A), (B) and (C) represents a 2 mm.times.2 mm section of an inner surface of the vapor chamber of a thermal conductivity and phase transition heat transfer mechanism. However, the different examples (A), (B) and (C) have different sizes and numbers of heat transfer elements extending into the interior of the chamber. In the illustrated views, the heat transfer elements appear as circles, representing the end view (from inside the vapor chamber) of cylindrical heat transfer elements. Cylindrical shapes are used here for ease of modeling, although as noted earlier, other shapes may be used. For purposes of this comparison, we will assume that the heat transfer elements are all formed of the same material in each and every one of the three examples in FIG. **5**.

The first example (A) has four pins of radius 0.25 mm (diameter of 0.5 mm). The length of the pins L need not be specified for comparison purposes. The number 4 in the formulae for the example is the number of pins. The volume of each pin is 2π times the radius squared times the length (L) of the pins. As shown, the total volume of the material of the four pins is $0.25^2*2\pi*L*4$, which equals 0.78 L. For purposes of calculation of the surface area, we will use the outer cylindrical surface only (without including the end surfaces) to somewhat simplify the calculations for the comparison. With that approach, the surface area of a cylindrical pin is the diameter times π; times the length. Hence, the total cylindrical outer surface area presented by the four pins at (A) would be $0.5*\pi*L*4$, which equals 6.2 L. The thermal resistance of each pin equals the pin radius times the thermal resistance R of the material from which the pins are formed. In the example (A) in which the radius of the pins is 0.25 mm, the thermal resistance of each pin is 0.25*R.

The second example (B) has sixteen (16) pins of radius 0.125 rum (diameter of 0.250 mm) of the same length L as in the previous example. As shown, the total volume of the material of the sixteen pins is $0.125^2*2\pi*L*16$, which again equals 0.78 L. Again, using only the cylindrical surface area for purposes of comparison (without including the end surfaces), the total cylindrical, outer surface area presented by the sixteen pins at (B) would be $0.25*\pi*L*16$, which equals 12.5 L. This decrease in size and increase in number of pins results in approximately doubling the surface area for heat transfer in comparison to example (A). The thermal resistance of each pin in example (B), equals 0.125*R, which is half the thermal resistance of example (A).

The use of nanowires in the wicking structure, particularly the semiconductor transducer **17** and/or or on the housing section **5** at the cold location **7**, increases both the surface area for heat transfer and reduces the thermal resistance of each heat transfer element. Increased surface area and decreased thermal resistance both contribute to improved heat transfer. Example (C) in FIG. **5** represents a nanowire configuration in which the 2 mm×2 mm area of the chamber wall has 9.9×10^9 nanowires, where the radius of each nanowire is 5×10^{-6} mm (5 nanometers) or the diameter of each nanowire is 10×10^{-6} mm (10 nanometers).

As shown at (C), the total volume of the material of the nanowires is $(5\times10^{-6})^2*2\pi*L*(9.9\times10^9)$, which again equals 0.78 L. Again, using only the cylindrical surface area for purposes of comparison (without including the end surfaces), the total cylindrical outer surface area presented by the nanowires at (C) would be $10\times10^{-6}*\pi*L*9.9\times10^9$, which equals (3.1×10^5)L, which is approximately 50,000 times more surface area for heat transfer than in first example (A). The thermal resistance of each nanowire in example (C), equals (5×10^{-6})*R, which is approximately 50,000 times lower than the thermal resistance of example (A).

Hence, the use of nanowires in the wicking structure at various points in the exemplary transducer apparatuses, mechanisms or light emitters discussed herein improves thermal transfer capabilities. At a hot location or interface, use of nanowires improves transfer of heat to the working fluid. At a cold location, use of nanowires, improves transfer of heat from the working fluid to the cold interface, e.g. for transfer through the interface to a heat sink, active cooling element or ambient air.

The use of the nanowires also helps with the wicking action. As noted, inter molecular forces between a liquid and the surface(s) of the wicking material around the liquid produce capillary action to move of the liquid form of the working fluid along or through the material. Increasing the surface area helps to increase the inter forces on the liquid form of the working fluid. Hence, use of nanowires as the wicking structure, with increased surface area as shown above, also increases the strength of the capillary action of the wicking structure on the liquid torr of the working fluid.

As noted earlier, a variety of different fluids may be used as the working fluid. Different fluids are used in various transducer apparatus configurations to support the heat transfer function, and in many of the examples, to serve as a carrier for phosphor and/or as a conductor. For examples of the transducer apparatus that do not use the fluid as a carrier for phosphor or as a conductor, fluids commonly used in prior heat pipes and the like may be used, particularly if sufficiently transparent to allow any light passage that may be desirable in the particular apparatus configuration. For a working fluid that would carry semiconductor nano-phosphor as the phosphor, examples of suitable fluids include acetone, methanol, ethanol and toluene, if the nano-phosphor is well encapsulated, water may be on option. Toluene may be a preferred choice for many phosphors, however, for cooler internal working temperatures, ethanol me be preferred. For a working fluid that would carry rare-earth-phosphor, examples of suitable fluids include acetone, methanol ethanol and toluene, although here water may be a preferred choice. For a working fluid that is also electrically conductive, examples of suitable fluids include salt water, ammonia and fluids from the class of transparent ionic liquids.

We will now turn to a discussion of more examples of the principles outlined above relative to FIGS. **1**A to **5**. In that regard, FIGS. **6**-**8** are examples of thermal conductivity and phase transition heat transfer mechanisms that incorporate active optical elements in the form of multilayer optical/electrical transducer.

Consider first the example of a mechanism or apparatus **41** that incorporates a LED or photodiode, as the active optical element. The drawing is a cross-sectional view of an example of an optical/electrical transducer apparatus **41**, which also is configured as a thermal conductivity and phase transition heat transfer mechanism. The apparatus **41** includes a semiconductor transducer **57**, in the form of a light emitting diode or light emitting transistor, or a photodiode or light responsive transistor, as the active optical element incorporated in the thermal conductivity and phase transition heat transfer mechanism. As is well known in the art, the semiconductor includes two or more layers of semiconductor materials doped with traces of impurities to determine the type and degree of semi-conductivity of each layer. The number of layers and the types of semiconductor formed at the various layers configures the semiconductor as a particular type of electronic device, that is to say, as a particular type of optical/electrical transducer in this example.

The transducer apparatus **41** includes a housing **43**. The housing **43** is formed of a metal section **45** and a light transmissive member **49**. In this example, the metal section **45** supports the semiconductor transducer **57**; and the light transmissive member **49** forms a curved cover or dome over but separated from the emitting portions of the semiconductor transducer **57**. Viewed from above or below, the apparatus could be circular, oval, rectangular, square or the like. The metal of section **45** may be reflective, but it is not optically transmissive in this example. The optically transmissive member **49** of the housing **43** may be formed of a material that is also thermally conductive, although it may not be as thermally conductive as the metal of section **45**.

The semiconductor transducer **57** is located at a roughly central area or region of the metal section **45**, in this example, and a hot location **63** is formed in the area within the chamber **51** where heat is produced by operation of a semiconductor transducer **57**.

One or more portions of the member **49** and/or section **45** provide one or more relatively cold interfaces, similar to that at the cold location in the example of FIG. **1**A. Although the apparatus **41** functions at various orientations, in the illustrated orientation, a cold interface or location would be formed at **67** along the surface of the curved optically transmissive member **49** of the housing **43**, although there may be other cold locations **67** within the chamber. The materials of the housing section **45** and member **49** may be similar to those of the section **5***a* and the member **9***a* in the example of FIG. **1**A, although other suitable materials may be used.

As in the earlier example, the optically transmissive member or section **49** is attached to the housing section **45** to form a seal for the vapor tight chamber **51**. For example, if the optically transmissive member or section **49** is a glass or ceramic material and the housing section **45** is formed of a metal, the two elements may be joined by a glass fit process or by application of a suitable epoxy.

The exemplary apparatus **41** also includes a working fluid within the chamber **51**. Again, the pressure within the chamber **51**, typically a pressure somewhat lower than atmospheric pressure, configures the working fluid to absorb heat during operation of the apparatus, to vaporize at the relatively hot location **63** as it absorbs heat from the transducer **57**, to transfer heat to and condense at the relatively cold location(s) **67**, and to return as a liquid to the relatively hot location **63**. A variety of different fluids may be used as the working fluid, and the pressure is determined based on the fluid type and the amount of heat that the fluid is expected to transfer.

The working fluid, in its liquid state, contacts the hot interface at the location **63** where the transducer **57** produces heat. For example, the working fluid directly contacts the one or more surfaces of the transducer **57** exposed to the fluid within the chamber **51**. As the liquid absorbs the heat, it vaporizes. The vapor fills the otherwise empty volume of the chamber **51**. Where the chamber wall is cool enough (the cold interface at one or more locations **67**), the vapor releases heat to the wall of the chamber **51** and condenses back into a liquid. The liquid form of the fluid flows back to the hot interface at location **63**. In operation, the working fluid goes through this evaporation, condensation and return flow to form a repeating thermal cycle that effectively transfers the heat from the hot interface to the cold interface.

Hence, as in the earlier examples, the apparatus **41** is configured as a thermal conductivity and phase transition heat transfer mechanism. The thermal conductivity of the housing **43** and the phase transition cycle through evaporation and condensation transfer heat from the hot location **63** to the cold locations **67**.

As in the earlier examples, the exemplary apparatus **41** also includes a wicking structure **55** mounted within the chamber **51** to facilitate flow of condensed liquid of the working fluid from the cold locations **67** to the hot location **63** of the mechanism. The capillary action of the wicking structure **55** can overcome other forces on the liquid, such as gravity, to promote a desired movement of the liquid, regardless of the orientation of the optical/electrical transducer apparatus **41**. The wicking structure may take many forms, as outlined in the discussion of the earlier examples, such as one or both of the nanowire arrangements of FIGS. **3** and **4**.

The orientation in the drawing, in which light enters the apparatus **41** or is emitted from the apparatus **41** to/from directions above the horizontal plane, is shown only for purposes of illustration. Those skilled in the art will appreciate that the apparatus **41** may be used in any other orientation that is desirable or suitable for any particular application of the transducer apparatus. As in the earlier examples, optical processing elements (not shown), such as diffusers, reflectors, lens and the like, may be coupled to the optically transmissive member **49** to process light directed into the transducer apparatus **41** or to process light emitted from the transducer apparatus **41**.

A first electrical connection path to a first layer of the semiconductor structure of the transducer **57** is provided via the conductive metal of the housing section **45**. An outer surface of another semiconductor layer of the transducer **57** may be can be coated with a transparent conductor like one of those discussed earlier, in this case, to provide a second electrical connection path to the semiconductor structure of the transducer **57**. Alternatively, the second electrical connection path can be provided via the working fluid, in which case, the working fluid is a conductive fluid.

As noted earlier in the discussion of FIG. **1**A, the transducer **57** can be configured as an electrical-to-optical light emitter or as an optical-to-electrical sensor or photovoltaic.

FIG. **7**A is another example of a thermal conductivity and phase transition heat transfer mechanism that incorporates an active optical element. The apparatus **41***a* of FIG. **7**A is an electroluminescent device for emitting light in response to an electrical current. At a high level, the device **41***a* is similar to a light emitting device application of the apparatus **41** of FIG. **6**, except that instead of the semiconductor transducer, the device **41** includes at least an electroluminescent (EL) phosphor **57***a* serving as the light emitting transducer.

The electroluminescent device **41***a* also is configured as a thermal conductivity and phase transition heat transfer mechanism. The device **41***a* includes a housing **43***a* formed of a metal section **43***a* and a light transmissive member **49***a*, of materials similar to the metal and optically transmissive; materials discussed above relative to the earlier examples. In this electroluminescent device example, the metal section **45** supports the electroluminescent transducer, including the electroluminescent phosphor **57***a*. The light transmissive member **49***a* forms a curved cover over but separated from the emitting portions of the light emitting phosphor **57***a*. In cross-section, the member **49***a* and section **45***a* form a housing **43***a* of rectangular shape. Viewed from above or below, the apparatus could be circular, oval, rectangular, square or the like. The metal of section **45***a* may be reflective, but it is not optically transmissive in this example.

As in the earlier example, the optically transmissive member or section **49** is attached to the housing section **45** to form a seal for the vapor tight chamber **51**. For example, if the optically transmissive member or section **49** is a glass or ceramic material and the housing section **45** is formed of a metal, the two elements may be joined by a glass frit process or by application of a suitable epoxy.

Electroluminescent devices are fabricated using thin films of either organic or inorganic materials between an anode and a cathode, in the form of one or more layers represented collectively by the layer **57***a* forming the electroluminescent transducer in the drawing. The thin film layers contain a bulk semiconductor (or host material for organic elegy) and a dopant which defines the visible color emitted. The semiconductor needs to have wide enough bandwidth to allow exit of the light. The most typical inorganic thin-film EL (TFEL), fix example, is ZnS:Mn with its yellow-orange emission. Examples of the range of EL material include: powder zinc sulfide doped with copper or silver, thin film zinc sulfide doped with manganese, natural blue diamond (diamond with boron as a dopant), III-V semiconductors—such as InP, GaAs, and GaN, and Inorganic semiconductors—such as $[Ru(bpy)_3]^2+(PF_6^-)_2$, where bpy is 2,2'-bipyridine.

In the example, the conductive base formed by the housing section **45***a* may serves as the cathode of the transducer **57***a*. An additional transparent conductive coating could be provided over the opposite surface of the thin film structure of the electroluminescent transducer **57***a* to serve as the anode. Alternatively, the working fluid may be conductive and provide the second path for electrical connection to the electroluminescent transducer **57***a* in place of a separate solid conductive anode.

The exemplary apparatus **41***a* also includes a working fluid within the chamber **51**. A variety of different fluids may be used as the working fluid, as in the earlier examples. The working fluid, in its liquid state, contacts the hot interface at the location the EL transducer **57***a* produces heat. As in the earlier examples, the exemplary apparatus **41***a* also includes a wicking structure **55***a* mounted within the chamber **51***a* to facilitate flow of condensed liquid of the working fluid from the cold location to the hot location of the mechanism. The capillary action of the wicking structure **55***a* can overcome other threes on the liquid, such as gravity, to promote, a desired movement of the liquid, regardless of the orientation of the optical/electrical transducer apparatus **41***a*. The wicking structure may take man forms, as outlined in the discussion of the earlier examples, such as one or both of the nanowire arrangements of FIGS. **3** and **4**. As in the earlier examples, the light emitting device **41***a* is configured as a thermal conductivity and phase transition heat transfer mechanism. The thermal conductivity of the housing **43***a* and the phase transition cycle through evaporation and condensation transfer heat from the hot location to the cold location.

The pressure within the chamber **51***a*, typically a pressure somewhat lower than atmospheric pressure, configures the working fluid to absorb heat during operation of the apparatus, to vaporize at the relatively hot location as it absorbs heat from the EL transducer **57***a*, to transfer heat to and condense at the relatively cold location, and to return as a liquid to the relatively hot location. In operation, the working fluid goes through this evaporation, condensation and return flow to form a repeating thermal cycle that effectively transfers the heat from the hot interface to the cold interface.

A first electrical connection path to a first layer of the thin film structure of the EL transducer **57***a* is provided via the conductive metal of housing section **45***a*. An outer surface of another layer of the thin film structure of the EL transducer **57***a* may be can be coated with a transparent conductor like one of those discussed earlier, in this case, to provide a second electrical connection path to the structure of the EL transducer **57**. Alternatively, the second electrical connection path can be provided via the working fluid, in which case, the working fluid is a conductive fluid.

The orientation in the drawing, in which light, is emitted from the EL device **41***a* to/from directions above the horizontal plane, is shown only for purposes of illustration. Those skilled in the art will appreciate that the apparatus **41***a* may be used in any other orientation that is desirable or suitable for any particular application of the transducer apparatus. As in the earlier examples, optical processing elements (not shown), such as diffusers, reflectors, lens and the like, may be coupled to the optically transmissive member **49***a* to process light directed into the transducer apparatus **41** or to process light emitted from the transducer apparatus **41***a*.

The example of the EL device in FIG. **7**A utilized a thin film structure fir the electroluminescent transducer **57***a*. An alternative approach might use a layer of an electroluminescent phosphor. Again, the conductive base thrilled by the housing section **45***a* may serve as the cathode, and an additional transparent conductive coating could be provided over the opposite surface of the electroluminescent phosphor to serve as the anode. Alternatively, the working fluid may be conductive and provide the second path for electrical connection to the electroluminescent phosphor in place of a separate solid conductive anode. If electrical paths are provided via the lateral ends of the phosphor layer, the inner surface of the layer may be exposed to the working fluid or may at most be covered by a minimal barrier layer as noted in several earlier examples.

FIG. **7**B depicts an electroluminescent device **41***a'* for emitting light in response to an electrical current, similar to the device **41***a* of FIG. **7**A. However, the device **41***a'* of FIG. **7**B uses a different structure for the actual electroluminescent emitter **57***a'*. Hence, the housing **43***a*, the optically transmissive member **45***a*, the thermally conductive housing section **49***a*, and the working fluid are essentially the same as in the example of FIG. **7**A, and like reference numbers have been used. The wicking structure **55***a'* will also include some portions, e.g. at least on the inner surfaces of the thermally conductive housing section **49***a*, that are the same as used on the corresponding surfaces in the device **41***a* of FIG. **7**A. However, the actual transducer **57***a'* in the example of FIG. **7**B includes nanowires, which serve both a light emitting function and as part of the wicking structure **55***d*. More specifically, the electroluminescent emitter **57***a* includes nanowire wick **56***b* that forms or serves as part of the actual electroluminescent emitter **57***a'*.

FIG. **7**C shows an example of a section of the electroluminescent emitter **57***a'*, utilizing the nanowire portion **56***a* of the wicking structure. The electroluminescent emitter **57***a'* includes a conductive base. The base may be formed of an appropriate conductive material. The base could be formed of a transparent conductor, e.g. if formed on the member **49***a* instead of on the housing section **45***a*, since the electroluminescent emitter **57***a'* is formed on the housing section **45***a*, and the conductive base need not be transparent. Although a separate base material may be provided as a layer on the housing section **45***a*, in the example, the metal of the housing section **45***a* serves as the conductive base of the emitter **57***a*.

The electroluminescent emitter **57***a'* also includes a nanowire wick **560** formed of individual nanowires **52** grown to extend out from the conductive base formed by the housing section **45***a*. Each nanowire **52** comprises a nanowire core conductor **54** for example, formed as a nanowire of the conductive material grown outward from the base/housing section **45***a*. The electroluminescent emitter **57***a'* also includes a coating layer of an electroluminescent phosphor, in this example, a quantum dot (QD) electroluminescent (EL) phosphor. The QD electroluminescent EL phosphor coating **58** is formed over the outer surfaces of the nanowire core conductors **54** and the intervening surface regions of the conductive base **45***a*. Hence, each individual nanowire **52** includes an outer nanowire coating of the QD electroluminescent phosphor over the nanowire core conductor **58**.

In the example, the conductive base formed by the housing section **45***a* serves as the cathode. An additional transparent conductive coating could be provided over the QD electroluminescent phosphor to serve as the anode. However, in the example, the working fluid **35***b* is conductive and provides the second path for electrical connection to the electroluminescent emitter **57***a'* in place of a separate solid conductive anode. The working fluid directly contacts the surfaces of the phosphor coating **58** exposed within the chamber, both for supply of electricity and far transfer of heat. Electrical power applied through the housing section **45***a* and the conductive working fluid **350** of sufficient voltage and/or current will drive the electroluminescent phosphor **58** to emit light, generally upwards in the orientation of the device **44***a*' shown in FIG. **7**B. In operation, however, the thermal conductivity and phase transition heat transfer mechanism operations of the device **41***a* (like those of earlier examples) will transfer heat away from the transducer, in this case, away from the light emitting electroluminescent phosphor **58** of the emitting transducer **57***a'*.

FIG. **6** represented an example of a device **41** that used a multilayer semiconductor such as a diode or transducer **57** for a light emitter or a light responsive transducer. The light emitting device **41***a* of FIGS. **7**A-**7**C utilized electroluminescent (EL) type emitters. Similar teachings, however, can be applied to other types of transducers. Another example of a light emitting transducer that may be incorporated in a thermal conductivity and phase transition heat transfer mechanism is an organic light emitting diode (OLED).

We will consider next FIG. **8**, which is a cross-sectional view of an example of an optical/electrical transducer **41***b* for light emitting applications, where the incorporated transducer is an OLED **57***b*. The light emitting device **41***b* includes a housing **431**. The housing **43***b* is formed of a metal section **45***b* and a light transmissive member **49***b*, of materials and joined together to form a chamber **51***b*, much like in the earlier examples. In this example, however, the light transmissive member **49***b* supports the OLED **57***b*.

An OLED, such as **57***b*, may include layers of organic material **60** situated between a transparent anode and a metallic cathode. An OLED can be fabricated on a sheet of glass or plastic, in this case, serving as the optically transmissive member **49***b*. In the example of FIG. **8**, a transparent conductor **59** on the optically transmissive member **49***b* would form the anode. Examples of suitable transparent conductors have been discussed above relative to an earlier example. The metallic cathode, shown at **61**, may be reflective. The organic layers comprise a hole-injection layer, a hole-transport layer, an emissive layer, and an electron-transport layer. When sufficient voltage is applied to the OLED the injected positive and negative charges combine in the emissive layer to produce light. The brightness of the light is proportional to current flow. The dopant defines the visible color emitted. The semiconductor needs to have wide enough bandwidth to allow exit of the light. The most typical inorganic thin-film EL (TFEL), for example, is ZnS:Mn with its yellow-orange emission. Examples of the range of EL material include: powder zinc sulfide doped with copper or silver, thin film zinc sulfide doped with manganese, natural blue diamond (diamond with boron as a dopant), III-V semiconductors—such as InP, GaAs, and GaN, and Inorganic semiconductors—such as $[Ru(bpy)_3]^2+(PF_6^-)_2$, where bpy is 2,2'-hipyridine. Different materials allow OLEDs to provide colors covering the visual spectrum, thereby obviating a need for filters.

In this example, the optically transmissive member **49***b* is shown in the firm of a flat plate or the like, although obviously other shapes may be used. OLEDs, for example, may be thrilled on curved or angle members. The metal section **45***b* in our example forms the rest of the rectangular cross-sectioned housing **43***b* over the non-emitting portions of the OLED **57***b*. Viewed from above or below, the light emitting device **41***b* could be circular, oval, rectangular, square or the like. The OLED **57**B is roughly coextensive with the area the optically transmissive member **49***b*, although the OLED or the member could extend somewhat beyond the other.

In this example, a hot location **53***b* is formed in the area within the chamber **51***b* where heat is produced by operation of the OLED **57***b*. The outer surfaces of the OLED **57***b* form the hot interface. One or more portions of the housing section **45***b* provides the relatively cold interfaces, similar to that at the cold location in the example of FIG. **1**A. Although the apparatus functions at various orientations, in the illustrated orientation, a cold interface or location would be formed at **67***b* at or near the upper or back surface of the thermally conductive section **45***b* of the housing **43***b*.

As in the earlier examples, the optically transmissive member or section **49***b* is attached to the housing section **45***b* to form a seal for the vapor tight chamber **51***b*. The exemplary apparatus **41***b* also includes a working fluid within, the chamber **51***b* as well as a wicking structure **55***b* to facilitate flow of condensed liquid of the working fluid from the cold location **67***b* to the hot location **53***b*. The working fluid, in its liquid state, contacts the hot interface at the location **53***b* where the light emitting device **41***b* produces heat, that is to say, by direct contact with the outer surfaces of the OLED **57***b* within the chamber **51***b* in this example. As in the earlier examples, the pressure within the chamber **51***b* configures the working fluid to absorb heat during operation of the apparatus, to vaporize at the relatively hot location **53***b* as it absorbs heat from the OLED **57***b*, to transfer heat to and condense at the relatively cold location **67***b*, and to return as a liquid to the relatively hot location **53***b*. Hence, as in the earlier examples, the light emitting device **41***b* is configured as a thermal conductivity and phase transition heat transfer mechanism. The thermal conductivity of the housing **43***b* and the phase transition cycle through evaporation and condensation transfer heat from the hot location **53***b* to the cold location **67***b*.

In this OLED example, first electrical connection path to the OLED structure of via connection (not shown) to the conductive anode **59**. If insulated, a conductive lead may provide a connection to the cathode **61**. Alternatively, the second electrical connection path can be provided to the cathode **61** via the working fluid, in which case, the working fluid is a conductive fluid.

The orientation in the drawing, in which the device **41***b* light downward around a substantially central axis of the device, is shown only for purposes of illustration. Those skilled in the art will appreciate that the apparatus **41***b* may be used in any other orientation that is desirable or suitable for any particular application of the transducer apparatus. As in the earlier example, optical processing elements (not shown), such as diffusers, reflectors, lens and the like, may be coupled to the optically transmissive member **49***b* to process light directed into the transducer apparatus **61** or to process light emitted from the light emitting device **41***b*.

FIG. **9**A is a cross-sectional view of an example of an optical/electrical transducer apparatus **71**, similar to that of FIG. **1**B, where the semiconductor transducer **87**, such as a LED or a photodiode, utilizes semiconductor nanowires **89** that also form to portion of the wicking structure **85** of the thermal conductivity and phase transition heat transfer mechanism that is an integral part of the transducer apparatus **71**.

The transducer apparatus **71** includes a housing **73**. The housing **73** is formed of a metal section **75** and a light transmissive member **79**. In this example, the metal section **75** supports the semiconductor transducer **87**; and the light transmissive member **79** forms a curved cover or dome over but separated from the emitting portions of the semiconductor transducer **87**. Viewed from above or below, the apparatus could be circular, oval, rectangular, square or the like. The metal of section **75** may be reflective, but it is not optically transmissive in this example. The optically transmissive section **78** of the housing **73** may be formed of a material that is also thermally conductive, although it may not be as thermally conductive as the metal of section **75**.

The semiconductor transducer **87** is located at a roughly central area or region of the metal section **75**, in this example, and a hot location **83** is formed in the area within the chamber where heat is produced by operation of a semiconductor transducer **87**.

One or more portions of the member **79** and/or section **75** provide one or more relatively cold interfaces, similar to that at the cold location in the example of FIG. **1**B. Although the apparatus functions at various orientations, in the illustrated orientation, a cold interface or location would be formed at **77**. A cold location may be along the surface of the curved optically transmissive section **79** of the housing **73**, although there may also be cold areas or interfaces at other locations **77** within the chamber. The materials of the housing section **75** and member **79** may be similar to those of the section **5** and the member **9** in the example of FIG. **1**B, although other suitable materials may be used.

As in the earlier example, the optically transmissive member or section **79** is attached to the housing section **75** to form a seal for a vapor tight chamber **81**. For example, if the optically transmissive member or section **79** is a glass or ceramic material and the housing section **75** is formed of a metal, the two elements may be joined by a glass frit process or by application of a suitable epoxy.

The exemplary apparatus **71** also includes a working fluid within the chamber **81**. Again, the pressure within the chamber **81**, typically a pressure somewhat lower than atmospheric pressure, configures the working fluid to absorb heat during operation of the apparatus, to vaporize at the relatively hot location **83** as it absorbs heat from the transducer **87**, to transfer heat to and condense at one or more relatively cold locations **77**, and to return as a liquid to the relatively hot location **83**. A variety of different fluids may be used as the working fluid, and the pressure is determined based on the fluid type and the amount of heat that the fluid is expected to transfer.

The working fluid, in its liquid state, contacts the hot interface at the location **83** where the apparatus receives or produces heat. For example, the working fluid directly contacts the outer surfaces of the nanowires **89**. As the liquid absorbs the heat, it vaporizes. The vapor fills the otherwise empty volume of the chamber **81**. Where the chamber wall is cool enough (the cold interface at locations **77**), the vapor releases heat to the wall of the chamber **81** and condenses back into a liquid. The liquid form of the fluid flows back to the hot interface at location **83**. In operation, the working fluid goes through this evaporation, condensation and return flow to form a repeating thermal cycle that effectively transfers the heat from the hot interface to the cold interface.

Hence, as in the earlier example, the apparatus **71** is configured as a thermal conductivity and phase transition heat transfer mechanism. The thermal conductivity of the housing **73** and the phase transition cycle through evaporation and condensation transfer heat train the hot location **83** and the cold locations **77**.

As noted, the exemplary apparatus **71** also includes a wicking structure **85** mounted within the chamber **81** to facilitate flow of condensed liquid of the working fluid from the cold location **87** to the hot location **83** of the mechanism. The capillary action of the wicking structure **85** can overcome other threes on the liquid, such as gravity, to promote a desired movement of the liquid, regardless of the orientation of the optical/electrical transducer apparatus **71**. The wicking structure may take many forms, as outlined in the discussion of the earlier examples.

As in the earlier example, the apparatus **71** includes a semiconductor type optical/electrical transducer **87** for converting between optical and electrical energy. The transducer in the example here is a diode, although the diode may be a light emitting diode or a photodiode. For an implementation using a photodiode form of the transducer **87**, light enters the apparatus **71** through the optically transmissive member **79**, impacts on the photodiode transducer **87** and causes the diode to generate a responsive electrical signal. For an electrical-to-optical conversion application, a drive current is applied to the light emitting diode of the transducer **47** causing it to generate light, which emerges from the apparatus **71** through the optically transmissive member **79**.

The orientation in the drawing, in which light enters the apparatus **71** or is emitted from the apparatus **71** to/front directions above the horizontal plane, is shown only for purposes of illustration. Those skilled in the art will appreciate that the apparatus **71** may be used in any other orientation that is desirable or suitable for any particular application of the transducer apparatus. As in the earlier example, optical processing, elements (not shown), such as diffusers, reflectors, lens and the like, may be coupled to the optically transmissive member **79** to process light directed into the transducer apparatus **71** or to process light emitted from the transducer apparatus **71**.

The transducer **87** may be formed in a manner similar to that of the transducer **17** in the examples of FIGS. **1**B and **2**, e.g. in the form of a conductive base with a semiconductor structure formed on the conductive base. The semiconductor structure in turn includes semiconductor nanowires, in the example of FIG. **9**A, nanowires **89**. In this example, the conductive base can be a metal or an appropriately doped semiconductive material. Unlike the earlier example of FIG. **2**, the conductive base need not be transparent.

A first electrical connection path to the semiconductor structure of the transducer **87** is provided via the conductive base. The outer surfaces of the semiconductor structure of the transducer **87**, including the outer surfaces of the semiconductor nanowires **89**, can be coated with a transparent conductor like one of those discussed earlier, in this case, to provide a second electrical connection path to the semiconductor structure of the transducer **87**. Alternatively, the second electrical connection path can be provided via the working fluid, in which case, the working fluid is a conductive fluid.

As in the example of FIG. **1**B, in the apparatus **71** of FIG. **9**A, the semiconductor nanowires **89** of the optical/electrical transducer **87** also serve as part of the wicking structure **85** for purposes of promoting the liquid flow in the phase transition cycle of the heat transfer mechanism.

In addition to the semiconductor nanowire portion **89**, the wicking structure **85** includes one on more portions **91** thrilled on inner surfaces of the chamber wall thrilled by the section **75** and the optically transmissive member **79**. The portions **91** of the wicking structure formed on the section **75** and the optically transmissive member **79** could be the same or different kinds of structures. The wicking structure in portions **91** may take many forms, as outlined in earlier discussions.

In the example, however, the portions **91** formed on inner surfaces of the chamber wall formed by the section **75** and the optically transmissive member **79** consist of nanowires formed on the appropriate surfaces. The nanowire wicking structures on the section **75** and the optically transmissive member **79** may be the same, e.g. similar to one of the structures discussed above relative to FIGS. **2** and **3**. In the example of FIG. **9**A, however, a first type of nanowire arrangement is provided for the portion **91***a* of the wicking structure on the metal housing section **25**, and a different type of nanowire arrangement is provided for the portion **91***b* of the wicking structure on the optically transmissive member **79**. For example, the first type of nanowire arrangement is provided for the portion **91***a* of the wicking structure on the metal housing section **25** may be a reflective metallic nanowire, configuration as in part of the discussion of FIG. **4** above. The second type of nanowire arrangement provided for the portion **91***b* of the wicking structure on the optically transmissive member **79** may be optically transmissive, although it may also contain a phosphor component for conversion of some of the light passing through the member **79** as discussed earlier relative to FIG. **3**. Phosphor may also be provided in the working fluid, if useful to support a particular application of the transducer apparatus **71**.

The number and size of the nanowires in the various sections **89**, **91***a* and **91***b* would be chosen to promote the desired capillary action as well as to achieve a degree of heat transfer appropriate for the particular transducer design.

For purposes of discussion of a first application of a transducer apparatus **71**, assume for now that the transducer apparatus **71** emits light, e.g. the transducer **87** is a LED. A substantial portion light emitted from the LED type transducer **87** is directed toward the optically transmissive member **79**. As it reaches the inner surface of the optically transmissive member **79**, some of that light excites phosphor(s) in the phosphor nanowires in the portion **91***b* of the wicking structure on the optically transmissive member **79**. The excited phosphors re-emit light of a different spectral characteristic, e.g. at a wavelength different from the excitation light. If provided, phosphor(s) in the working fluid may be similarly excited to produce light of an additional spectral characteristic. Output light of the apparatus **71** includes a combination of light directly emitted by the LED type transducer **87** and light produced by phosphor excitation. The use of phosphors may shift light from a wavelength region that does not substantially contribute to the intended application into a more desirable/useful wavelength region, e.g. from ultraviolet (UV) or near UV up into the more desirable visible part of the spectrum. This may improve efficiency or efficacy of the overall light output of the apparatus **71**.

In the light emitting application of a transducer apparatus **71**, some light emitted by the LED type transducer **87** is directed toward the metal section **75**. If phosphors are provided in the wicking structure and/or the working fluid, then some of the light produced by phosphor excitation also is directed toward the metal section **75**. The metal of the section **75** may be reflective, to redirect such light for output via the optically transmissive member **79**. However, in the example, much of the inner surface of the metal section **75** is covered by the portion **91***a* of the wicking structure formed of reflective metallic nanowires. Hence, the metal nanowires of the portion **91***a* redirect light for output via the optically transmissive member **79**.

Much like the example of FIGS. **1**B-**3**, the arrangement of FIG. **9**A is also suitable for use in a sensor or photovoltaic application in which the transducer **87** is a photodiode. The optical-to-electrical application would function essentially in reverse of the preceding discussion of the electrical-to-optical emitter application. For example, light entering via the member **79** would be processed by phosphors (if provided) and/or reflected. Then, upon impact on the photodiode type transducer **87**, the light would cause the transducer **87** to generate electricity as the light responsive output of the apparatus **71**.

FIG. **9**B is a cross-sectional view of a lamp that incorporates the principles of FIGS. **1**B, **2** and **9**A. Although shaped differently, the lamp of FIG. **9**B is very similar to the device of FIG. **9**A. The device includes a heat dissipation element that is also optically transmissive. The nanowire LED structure is mounted on a thermally conductive and not light transmissive housing section, which in the example of FIG. **9**B also forms a pedestal for the nanowire LED structure. The thermally conductive pedestal/housing member and the optically transmissive member/heal dissipation element are joined in such a manner as to form a vapor chamber for the thermal conductivity and phase transition heat transfer mechanism. A wicking structure for facilitating the flow of the working fluid is formed on the surfaces forming the chamber walls, on both the optically transmissive member and the thermally conductive pedestal/housing member.

The example in FIG. **9**B is shown in the form of a candelabra lamp or light bulb. A standard lamp base connects to the pedestal, and circuitry (not shown) within, the base and/or pedestal would provide power to drive the nanowire LED structure, derived from battery supply or AC mains power received via the base. It is believed that one of skill in the art will appreciate the structure and operation of the lamp of FIG. **9**B from the illustration and from the description of related examples above with regard to FIGS. **1**B, **2** and **9**A. Of course those skilled in the art will appreciate that the concepts of FIGS. **1**B, **2** and **9**B can be adapted to other lamp and fixture configurations and are not just limited to the illustrated examples.

FIGS. **6**-**8** were examples of application of the principles of the apparatus of FIG. **1**A. FIGS. **9**A-**9**B were examples showing application of the principles of the apparatus of FIG. **1**A. The example of FIG. **1**C involved incorporation of a phosphor in the mechanism but assumed that the source was outside of the mechanism **1***c*, although in that high-level example, the source was omitted. It may be helpful now to consider an example of a lighting device or system that incorporates a source and a thermal conductivity and phase transition heat transfer mechanism with a phosphor, with reference to FIGS. **10**A to **11**.

An opto-luminescent phosphor may be used with an optical/electrical transducer, both in the context of a light generating or emitting application and in the context of a light responsive electrical signal or power generation application. For example, the mechanism **1***c* may be used with a light source to generate light, or the mechanism **1***c* may be used with a light responsive transducer to sense or otherwise response to light from some other source processed by the phosphor within the mechanism. An opto-luminescent phosphor may convert energy from a source to a different wavelength range, to make a light output of an emitter more efficient and/or to provide a more desirable spectral characteristic in the output of the device. An opto-luminescent phosphor may convert energy from a light input to different wavelength range to which a sensor or photovoltaic device may be more responsive, to improve sensitivity of the transducer. In many cases, the configuration of the phosphor deployment relative to one or more transducers may be very similar. We will consider an example of a phosphor deployment in a thermal conductivity and phase transition heat transfer mechanism with respect to FIGS. **10**A-**10**C. Although as noted, the configuration may be applied in the context of an optical-to-electrical conversion, in the discussion of the example illustrated in these particular drawings, we will concentrate on a light generation application.

Hence, FIG. **10**A is a back view of an example of a light emitting device or light engine **131**, FIG. **10**B is a cross-sectional view of an example of the light emitting device or light engine **131** oaken along line B-B of FIG. **10**A), and FIG. **10**C is an end or plan view of the light emitting device or light engine **131**. The light emitting device **131** includes a source **133** and a thermal conductivity and phase transition heat transfer mechanism **135** that incorporates an opto-luminescent phosphor within the thermal conductivity and phase transition heat transfer mechanism **135**. The light emitting device or light engine **131** also includes a heat sink **137**.

In this example, the source **133** is outside of the thermal conductivity and phase transition heat transfer mechanism **135** but coupled to supply optical excitation energy to the mechanism **135** for optical excitation of the phosphor within the mechanism **135**. The source may be tiny type of light emitter configured to supply optical energy in a wavelength range that includes at least a portion of the excitation hand of the phosphor included within the mechanism **135**. Examples of suitable sources include laser diodes and electroluminescent devices. However, most examples of the source **133** are solid state devices, including a wide range of devices referred to as light emitting diodes (LEDs).

As discussed herein, in this specific example but also with regard to other solid state emitter examples, applicable solid state light emitters essentially include any of a wide range light emitting or generating devices formed from organic or inorganic semiconductor materials. Examples of solid state light emitters include semiconductor laser devices and the like. Many common examples of solid state emitters, however, are classified as types of "light emitting diodes" or "LEDs." This exemplary class of solid state light emitters encompasses any and all types of semiconductor diode devices that are capable of receiving an electrical signal and producing a responsive output of electromagnetic energy. Thus, the term "LED" should be understood to include light emitting diodes of all types, light emitting polymers organic light emitting diodes (OLEDs), and the like. LEDs may be individually packaged, as in the illustrated example. Of course, LED based devices may be used that include a plurality of LEDs within one package, for example, multi-die LEDs that contain separately controllable red (R), green (G), blue (B) LEDs or the like, within one package. Those skilled in the art will recognize that "LED" terminology does not restrict the source to any particular type of package for the LED type source. Such terms encompass LED devices that may be packaged or non-packaged, chip on board LEDs, surface mount LEDs, and any other configuration of the semiconductor diode device that emits light. Solid state lighting elements may include one or more phosphors and/or nanophosphors, which are integrated into elements of the package to convert at least some radiant energy to a different more desirable wavelength or range of wavelengths.

The drawings show a single source, e.g. a single LED, OLED, laser diode, semiconductor nanowire light emitter, or electroluminescent device, at **133**. However, those skilled in the art will appreciate that many light engine designs for the device **131** may include a number of similar or different sources, as required to provide sufficient light far a particular application of the light engine **131**.

As in the earlier example of FIG. **1**C, the mechanism **135** includes a housing **136** having a section **138** that is thermally conductive and two members **139** and **140** that are at least partially optically transmissive. Although other shapes or configurations may be used, the example of FIGS. **10**A-**10**C utilizes a cylindrical configuration of the mechanism **135** similar to that of FIG. **1**C, but where the cylinder is somewhat flattened or disk shaped so that the axial dimension of the cylinder is smaller than the radial dimension of the cylinder. The optically transmissive members **139** and **140** appear flat in cross-section, although they could have other cross-sectional configurations, e.g. convex or concave, if a particular shape would promote light input or light output for a particular application. Larger or additional optically transmissive members and/or members of different lateral shapes may be provided, e.g. to facilitate light input and/or output in a light engine using additional sources. The materials and the thermal and optical properties of the thermally conductive section **138** and the optically transmissive members **139**, **140** forming the housing **136** can be similar to those discussed above relative to similar elements in the example of FIG. **1**C.

The orientation in FIG. **10**B, in which light enters the mechanism **135** and is emitted from the mechanism **135** in the left to right direction about as somewhat horizontal central axis, is shown only liar purposes of illustration. Those skilled in the art will appreciate that the light engine may be used in any other orientation that is desirable or suitable for any particular application of the mechanism **135**.

The optically transmissive members **139**, **140** are attached to the housing section **138** to form a seal for a vapor tight chamber **141**. For example, if the optically transmissive members **139**, **140** are formed of a glass or ceramic material and the housing section **138** is formed of a metal, the different elements may be joined by a glass frit process or by application of a suitable epoxy.

The heat sink **137** in this example is formed from two pieces **137***a* and **137***b*, which together form a tight-fitting cavity enclosing, the housing section **138** of the mechanism **135**. For ex aril pie, the pieces **137***a* and **137***b* form a cylindrical cavity of approximately the same outer size and shape as the thermally conductive section **138** of the housing **136**, so that when assembled as shown, the heat sink **137** provides structural support for the mechanism **135** and contact of the section **138** with the pieces **137***a* and **137***b* provides efficient thermal conductivity for heat transfer from the section **138** of the housing **136** to the heat sink **137**.

As shown in FIG. **10**A, the piece **137***a* of the heat sink **137** includes a core **143** and radially extending fins **145** for radiating heat to the ambient environment, in this case to the surrounding atmosphere. Straight radial fins are shown, for convenience, although other shapes/contours may be used for the fins, e.g. to improve transfer of heat to the ambient atmosphere. The core **143** of the heat sink **137** includes an indentation of an appropriate size and shape for securely holding the source **133**. For example, the outer canister of the source **133** may serve as the heat slug for the source **133**, and the canister of the source **133** may be press fitted into the indentation in the core **143** of the heat sink **137**. The mounting of the source **133** in this way provides both structural support for the source **133** and efficient thermal conductivity for heat transfer from the source **133** to the heat sink **137**.

The light output of the source **133** is coupled to the optically transmissive member **139** through a passage or aperture **147** through the core **143** of the first piece **137***a* of the heat sink **137**. In this way, the source **133** supplies light, including at least some phosphor excitation energy, into the mechanism **135**. The optically transmissive member **140** is coupled to a passage or aperture **149** through the second piece **137***b* of the heat sink **137**. In this way, light from the source **133** and/or from excitation of phosphor within the chamber **141** of the mechanism **135** emerges through the optically transmissive member **140** and the passage **149**. Each passage or aperture **147**, **149** may be a physical opening as shown, or each passage or aperture **147**, **149** may be formed of or include another optically transmissive element, such as a window, a lens, a holographic diffuser, a color filter or the like. The inner surfaces of the passages **147**, **149** may be reflective, e.g. specular or diffusely reflective, to minimize loss of light.

Of course, the shape of the depicted elements and the arrangement of parts, in this case for the source, the mechanism and the heat sink, are given here by way of example only. Those skilled in the art will appreciate that other sizes, shapes, arrangements, etc. may be used for particular light engine applications. For example, FIG. **10**B shows a relatively straight path from the source **133** through the two members **139**, **140** and out the optical passage **149**. For some applications, there may be additional members/paths/passages and/or the elements may be arranged to provide a somewhat angled or curved light transmission path.

As in the example of FIG. **1**C, the mechanism or device **135** also includes an opto-luminescent phosphor contained within the chamber **147** for emitting light when excited by optical pumping energy from the source **133**. The phosphor is the active optical element of the mechanism or device **135**. The particular phosphor of one or more different types is similar to the phosphor discussed above relative to the example of FIG. **1**.

The arrangement of the phosphor in the mechanism or device **135** and the separate mounting of the source **133**, with optical coupling there between, provide a form of "remote" deployment of the phosphor relative to the source **133** in that the phosphor is outside of the package enclosing the actual semiconductor chip or other light emitter of the source **133** and thus is apart or remote from the actual light emitter(s). The housing **138** containing the phosphor may be located at any convenient distance in relation to the light output of the source **133**. For example, there may be a separation as shown between the light output of the source **133** and the nearest optically transmissive member **139**. As another example, to provide efficient coupling of the light from the source **133** to the mechanism **135**, the light output of the source **133** may be adjacent to the optically transmissive member **139** so that they are in direct contact or so that there is contact through an index of refraction matching material, such as an optical gel or optical adhesive.

The phosphor may be provided in the chamber **141** in a variety of different ways, including some ways outlined above. For example, the phosphor may be provided in the mechanism **135** as a layer formed on the inner surface of either one or both of the optically transmissive members **139**, **140**, similar to the layer **17**_c_ in the example of FIG. **1**C. Another approach to the phosphor deployment would be to include the phosphor in the working fluid **141**. The light engine **131** also includes a wicking structure **150** mounted within the chamber **141** to facilitate flow of the condensed liquid of the working fluid from the cold location(s) to the hot location of the mechanism **135**. The example of FIGS. **10**A-**2**D incorporates the phosphor in the wicking structure, in a manner similar to the implementation discussed earlier, with respect to FIG. **3**.

As in the earlier example, a portion of the chamber **141** within the housing section **138** will form a cold location **153** within the chamber **141**, and the housing section **138** in that location forms a cold interface for transfer of heat to the heat sink **137**. In the example of FIGS. **10**A-**10**C, the cold location **153** is formed around the periphery of the chamber **141**, such that the outer periphery of the cylindrical section **138** of the housing serves as the cold interface. The relatively hot location **155** is in and possibly somewhat around the central region of the chamber between the optically transmissive members **139**, **140**. Phosphors in the wicking structure and/or fluid along the inner surfaces of the optically transmissive members **139**, **140** would be at the hot location from which the thermal conductivity and phase transition heat transfer mechanism transfers heat.

As noted, the exemplary light engine **131** also includes a working fluid **151** within the chamber **141**. The working fluid **151** is directly in contact, with at least a portion of the opto-luminescent phosphor **17**, in this example, within the wicking structure on one or both of the optically transmissive members **139**, **140** and/or contained within the fluid itself. The pressure within the chamber **141**, typically a pressure somewhat lower than atmospheric pressure, configures the working fluid **151** to absorb heat during operation of the light engine **131**, including heat from the phosphor produced by phosphor excitation and/or received from the source **133**. The working fluid **151**, in its liquid state, contacts the hot interface at the location **155** where the mechanism **135** receives or produces heat. In the example, the working fluid directly contacts at least some surface area(s) of the phosphor at or near the hot location **155**. When heated at the relatively hot location **155**, the working fluid **151** vaporizes. The vapor flows outward to the periphery of the chamber **141** to the cold location(s) **153** at the periphery of the chamber **151** in this example. At the cold location(s) **153**, heat is transferred from the vapor to the wall of the section **138** of the housing and from there to the heat sink **137** for dissipation to ambient air and/or via an external cooling system (not shown). The transfer of heat to the housing section **138** causes the vapor to condense back to the liquid form, at the relatively cold location(s) **153**. Through the capillary action of the wicking structure **150**, the liquid form of the working fluid **151** flows to the relatively hot location **155** at the center of the mechanism **135**. A variety of different fluids may be used as the working fluid, and the pressure is determined based on the fluid type and the amount of heat that the fluid is expected to transfer.

The mechanism **135** within the light engine **131** in the example thus is configured as a thermal conductivity and phase transition heat transfer mechanism. The thermal conductivity of the housing section **138** and the phase transition cycle through evaporation and condensation transfer heat from the hot location **155** to the cold location(s) **153**. Thermal conductivity at the cold interface allows heat transfer away from the mechanism, e.g. through the heat sink to ambient air.

As shown by the discussion of FIGS. **10**A-**10**C, the mechanism **135** in the light engine **131** includes a wicking structure **150** mounted within the chamber **141** to facilitate, the flow of condensed liquid of the working fluid **151** from the cold location(s) **153** to the hot location **155** of the mechanism **135**. As in the earlier examples, the wicking structure **150** may take many forms. The spacing between elements of the wicking structure **150** is sufficiently small to cause inter-molecular forces on the liquid form of the working fluid **151** to cause the liquid to flow toward the region where the fluid vaporizes, that is to say, the hot location **155** in the mechanism **135**. This wicking or capillary action enables the liquid form of the working fluid to flow back to the hot location regardless of the orientation of (and thus the impact of gravity on fluid in) the heat transfer mechanism **135**.

Although other wicks may be used on the members **139**, **140** and/or the housing section **138**, in the example, the mechanism **135** uses wicks for the structure **150** that utilize nanowires, like those discussed above relative to FIGS. **3** and **4**.

Also as noted above, the mechanism **135** includes an active optical element, in this case, a phosphor within the chamber **141** that is to be cooled by the thermo-dynamic operation of the combined phase transition heat transfer mechanism. At least a portion of a surface of the phosphor is directly contacted by the working fluid **151** at the location **155** where the fluid evaporates as it absorbs heat. The phosphor may be provided in the chamber in a variety of different ways, for example, as a layer like that in FIG. **1** or carried by the working fluid **151**. However, for purposes of further discussion of the example of FIGS. **10**A-**2**E, we will consider an arrangement in which the phosphor forms or is carried by material forming a nanowire structure serving as a portion of the wicking structure **150** of the mechanism **135**. Other portions of the wicking structure **150** may have other structures or characteristics, although the specific example below will concentrate on an arrangement in which some or all of the other portions of the wicking structure **150** are at least somewhat reflective.

FIG. **10**B shows partially enlarged views of sections E-E and D-D of the chamber wall and associated wicking structures at two different exemplary locations. The view D-D corresponds to a location on one of the optically transmissive members, for example, of member **140**; whereas the view E-E corresponds to a location on the thermally conductive section **138** of the housing of the mechanism **135**.

Hence, the enlarged detail view D-D in FIG. **10**B shows phosphor bearing nanowire wick **150**A formed on a portion of the optically transmissive member **140**. Phosphor may be similarly provided in the wick on the optically transmissive member **139**. The phosphor bearing nanowire wick **150**A may be similar to that shown in FIG. **3**. The enlarged detail view E-E in FIG. **10**H thaws a metallic nanowire wick **150***b* formed on a portion the thermally conductive housing section **138**, which may be similar to that show in FIG. **4**. The detail views also show a portion of the working fluid **151**.

Thermal conductivity and phase transition heat transfer mechanisms that incorporate phosphor materials to be cooled by operation of the mechanisms under discussion herein can be used in a variety of different types of light emitting devices, apparatuses and systems. The light engine **131**, for example, may be incorporated into various designs for light bulb type lamps; floor, desks or table lamps; light fixtures; displays; as well a lamps and fixtures for use in vehicles.

To help illustrate, consider the simplified example of FIG. **11**, which is a cross-sectional view of an example of a light fixture **161** incorporating a light engine **131** like that shown in FIG. **10**B. The fixture **161** thus includes the light engine **131** for producing the light intended for output from the fixture **161** together with one or more passive optical processing elements, such as diffusers, reflectors, lens and the like, optically coupled to the output aperture or passage **149** of the light, engine **131**.

In the example, the additional passive optical processing elements optically coupled to the output aperture or passage **149** include a reflective coating or disk **163** on an output face of the light engine **131** and surrounding the optical output aperture **149** (through the second piece **137***b* of the heat sink **137** in FIGS. **10**B and **10**C). The passive optical processing elements of the fixture **161** also include a truncated conically shaped reflector **165** and a diffuser **167**. The proximal end of the truncated cone of the reflector **165** connects to or matches with the outer periphery of the reflective coating or disk **163**. The diffuser **167** is located at or near the distal end opening of the reflector **167**.

The reflective surfaces of the reflective disk **163** and the reflector **165** may be specular, quasi-specular or diffusely reflective. Although shown as separate components, the reflective disk **163** and reflector **165** may be formed as a single unified reflective element. Also, the elements **163**, **165** are shown as relatively flat cross-sectional shapes, although one or both may be curved or form angles. For example, the disk **163** and reflector **165** may be configured to form a parabolic reflector, to provide a more beam-shaped output of the fixture **161**.

The diffuser **167** may be a translucent white material, which passes and diffuses some light and tends to diffusely reflect some light back within the optical chamber formed by the reflective disk **163**, the reflector **165** and the diffuser **167**. If the reflective disk **163** and the reflector **165** are diffusely reflective, the chamber may perform at least some optical integration of light from the source and the phosphor before emission of light via transmission through the diffuser **167**.

The disclosed fixture **161** may use as variety of different structures or arrangements for the disk **163**, reflector **165** and diffuser **167**. For efficiency, the reflective surfaces of the disk **163** and of the reflector **167** should be highly reflective. In the example, the light engine **131** is arranged in the fixture **161** so as to emit most of the light energy toward the diffuser **167**. To increase the optical integration and reduce possible pixilation or striation, the light engine **131** is arranged in the fixture **161** so as to emit light toward a reflective surface in such a manner that direct emissions form the aperture **149** are not directed to a transmissive output portion of the fixture (not directly toward the diffuser **167** in our example).

The orientation in the drawing, in which tight from the engine **131** is emitted downward, is shown only for purposes of illustration. Those skilled in the art will appreciate that the light fixture **161** may be used in any other orientation that is desirable or suitable for any particular application.

Fixtures of the type shown in FIG. **11** may combine the source, the reflector/diffuser elements and the thermal conductivity and phase transition heat transfer mechanism **135** that incorporates an opto-luminescent phosphor in a variety of other configurations. The remote phosphor may be provided in or about the optic formed by the source and the reflector/diffuser elements in any of a number of different ways or locations. For example, in another configuration, the thermal conductivity and phase transition heat transfer mechanism might have a reflective inner walled thermally conductive section with the phosphor deployed on the thermally conductive member and otherwise shaped like the combined reflector formed by **163** and **165** in the example of FIG. **11**. Light reflected within the chamber would pump the phosphor and be reflected for passage through the diffuser **167**.

As discussed, FIG. **11** represents an example of a light fixture. Although not shown, a lighting system that uses the engine **131** would include the engine and other elements forming; the fixture or the like, in combination with appropriate electronics to drive the particular source **133**. For example, if the source **133** includes one or more solid state light emitters, such as one or more LEDs, then the electronics would include a power supply for deriving DC power from the main source (DC battery or AC main lines) and driver circuitry for converting the derived DC to a form appropriate to drive the particular solid state emitter(s) at the output level appropriate for the intended lighting application. The power supply and driver circuitry are omitted from this and later examples for convenience, although those skilled in lighting will be quite familiar with such system components.

FIG. **12** is a top view and FIG. **13** is a side view, of a linear downlight utilizing an OLED in a thermal conductivity and phase transition heat transfer mechanism. FIG. **14** is to cross-sectional view of the linear downlight taken along line A-A of FIG. **13**, although FIG. **14** is not drawn to the same scale as are FIGS. **12** and **13**. FIG. **15** is an enlarged detail view of portions of the metal housing section, the OLED and the wicking structure, corresponding to that encircled by the arrow B-B in FIG. **14**. Although shaped differently, the OLED based light emitting device of FIGS. **12-15** is very similar to the device **41***b* of FIG. **8**.

The optical/electrical transducer for emitting light includes a thermally conductive metal housing section, an optically transmissive member or window, and an OLED; although in the example of FIGS. **12-15**, the OILED is mounted on the metal housing section rather than the optically transmissive member. A heat sink is attached to the surface of the metal housing section opposite the chamber (on the upper surface in the orientation illustrated in FIG. **14**).

In this example, the thermally conductive metal housing section is shown in the form of a rectangular flat plate or the like, although obviously other shapes may be used. The fixture may be three or four feet long, for example, for replacement of or substitution for a fluorescent light fixture. Here, the optically transmissive member is an elongated rectangular member having an upper shape matching the length and width of the metal housing, but the optically transmissive member has a curved cross-section (see FIG. **14**) covering and separated from the OLED. As in the earlier examples, the optically transmissive member or window is attached to the metal thermally conductive housing, section to form a seal for the vapor tight chamber. A hot location/interface is formed at the surface of the OLED where the OLED emits light downward, and cold locations are formed at the opposite portion of the chamber adjacent the optically transmissive member as well as locations somewhat away from the OLED along lateral regions of the housing section.

In this example, the metal housing section has a reflective surface where it supports the OLED and facing downward within the chamber. The metal housing section may provide an electrical connection to the OLED, although the example shows one or more leads for the electrical connections. The working fluid in this example is conductive, to carry current from one of the leads to the OLED.

The materials and manner of assembly of the light emitting transducer of FIGS. **12-15** are similar to those of earlier examples. The light emitting transducer of FIGS. **12-15** operates to emit light as well as to dissipate heat, essentially in the same ways as does the OLED based light emitter of FIG. **8**.

FIG. **16** is a top view of a downlight utilizing a free-standing, substrate free LED capable of emitting light from both sides of the diode structure, such as an EpiChip™ from Goldeneye, Inc. A transparent divider supports the LED, and the divider and LED together divide the interior of the downlight into two vapor tight chambers. Opposite sides of the LED are exposed to working fluids in the two chambers. The divider is also electrically insulating, and the conductive working fluids in the two chambers provide two current flow paths to/from the respective sides of the LED. The fluids are of sufficient quantity to form pools in contact with and fully immerse the side surfaces of the LED. FIG. **17** is a cross sectional view taken along line C-C of FIG. **16**. This example requires an orientation like that shown in FIG. **17**, in which gravity causes the fluid to pool at the lower portions of the chambers and thus immerse the LED so as to provide electrical conductivity to the LED while absorbing heat from the LED during operation As shown in that drawing, the luminaire emits light generally downward, and some light will be emitted laterally. FIG. **18** is a cross sectional view taken along line D-D of FIG. **16**, FIG. **19** is an enlarged detail view of the section of the downlight encircled by the arrow F in FIG. **18**, showing a portion of the wicking structure on the interior surface of the optically transmissive member or lens; and FIG. **20** is an enlarged detail view of portions of the divider and of the LED encircled by the arrow E in FIG. **18**. Reference now is made in detail to the example illustrated in FIGS. **16-20**.

The example of a downlight apparatus or luminaire **241** incorporates a LED **257**, as the active optical element. The apparatus **241** also is configured as a two-chambered thermal conductivity and phase transition heat transfer mechanism, that is to say providing phase transition and heat transfer in both chambers **251***a* and **251***b* formed on opposite sides of a wall provided by a divider **252** and the two-sided LED **257** incorporated into the divider **252**.

The apparatus **241** includes a housing, in this case, in the form of a sealed lens **243** formed of two sections or members **245** and **249**. The flat upper section **245** of the housing lens **243** serves as the thermally conductive section and is attached or otherwise thermally coupled to a heat sink **246**. In this example, the light transmissive member **249** takes the form of a somewhat elongated dish-shaped section of the lens/housing **243**, with one flattened end.

The inner surface of the thermally conductive section **245** is reflective, either due to the material of the section **245** or by virtue of a reflective surface coating. Hence, the lower surface of the section **245** forms a downward facing reflector **248** for the luminaire **241**.

The wall formed by the divider **252** and LED **257** is located between the inner surfaces of the housing section **245** and the transmissive member **249** of the lens so as to divide the dish into two chambers **251***a* and **251***b*. The thermally conductive housing section **245** and the optically transmissive member **249** may be formed of materials used for transmissive members in the earlier examples, or the section **245** may be formed of a material used for a thermally conductive section in earlier examples. The divider **252** is optically transmissive and may be formed of a suitable one of the materials used for optically transmissive members in the earlier examples. The housing section **245**, the optically transmissive member **249** and the divider **252** are joined together using techniques discussed earlier, to form the vapor tight seals for the two chambers **251***a* and **251***b*, with respect to the outside ambient environment as well as between the two chambers **251***a* and **251***b*.

The LED **257** is located in a lower region of the transparent divider **252**. One major conductive and emitting surface of the LED **257** is exposed in each chamber **251***a*, **251***b*. FIG. **17** shows the LED **257** as an elongated structure running along a substantial portion of the divider **252**. For such a configuration, the LED may be a single chip or a number of similar but smaller LEDs arranged side-by-side but fairly close together. Of course, other configurations or arrangements may be used to provide an amount of light generation and a light source profile that is desirable for a particular application of the luminaire **241**.

In the example, the section **245** coupled to the heat sink **246** provides the cold interfaces. Hence, the upper portion of each chamber **251***a*, **251***b* will form the relatively cold locations in the respective chamber. The major LED surface in each chamber will be a hot interface at a hot location in the respective chamber **251***a* or **251***b*.

The exemplary apparatus **241** also includes a working, fluid **265** within each of the chambers **251***a*, **251***b*. Again, the pressure within each chamber configures the working fluid **265** to absorb heat during operation of the luminaire **241**, to vaporize at the relatively hot location adjacent the LED surface in the respective chamber as the fluid absorbs heat from the LED **257**, rise out of the pool of liquid to fill the remainder of the chamber as a vapor, to transfer heat to and condense hack from vapor to liquid at the relatively cold location(s), and to return as a liquid to the relatively hot location. A variety of different fluids may be used as the working fluid, and the pressure is determined based on the fluid type and the amount of heat that the fluid is expected to transfer. Hence, much like earlier examples, each chamber of the luminaire **241** is configured as a thermal conductivity and phase transition heat transfer mechanism. The thermal conductivity of the housing **243** and the phase transition cycle through evaporation and condensation transfer heat from the hot locations to the cold locations for dissipation to the ambient environment via the heat sink **246**.

Because of the orientation, a wicking structure may or may not be provided in a luminaire like **241**. As in the earlier examples, however, the exemplary luminaire **241** also includes a wicking structure (see FIG. **19**) may mounted within each chamber **251***a*, **251***b*. Although the wicking structure may be formed on surfaces of the LED **257** as in earlier examples, as illustrated, the wicking structure is formed only on other surfaces forming the interior walls of the chambers and not on the exposed surfaces of the LED **257**, particularly surfaces above the expected level of the liquid pools. In this example, there is a sufficient amount of working fluid in each of the chambers **251***a*, **251***b* to form a pool covering the exposed surfaces of the LED **257**, therefore wicking structure on those surfaces may be omitted. However, as in the earlier examples, if provided, die wicking structure facilitates flow of condensed liquid of the working fluid from the cold locations back to the pools surrounding the hot locations **263** in the respective chambers **251***a*, **252***b*. The wicking structure may take many forms, as outlined in the discussion of the earlier examples.

The free-standing, substrate free LED **257** emits light from both its major surfaces when power is applied to those surfaces. Conductive leads could be provided to carry electricity to/from the surfaces of the LED **257** in the respective chambers **251***a*, **251***b*. However, in the example, the working fluid **265** is conductive and provides the electrical connection paths to the opposite surfaces of the LED **257** exposed in the respective chambers **251***a*, **251***b*. A lead or other means may be provided to supply power to the conductive working fluid in each chamber. When a voltage is applied across the electrically isolated pools of liquid in the two chamber **251***a*, **251***b* the voltage is applied through the liquid pools to the opposite surfaces of the LED **257**. If the voltage is sufficiently high to cause current to flow through the diode of the LED, the LED **257** will unit light from both its major surfaces. The emitted light flows through the liquid **265**. If directed toward the member **249** or if reflected down from the reflector **248**, the light passes through the optically transmissive member **249** as a light output of the luminaire.

FIG. **21** is a top view and FIG. **22** is a side view, of a linear downlight utilizing an electroluminescent (EL) device in a thermal conductivity and phase transition heat transfer mechanism. FIG. **23** is a cross-sectional view of the linear downlight taken along line A-A of FIG. **22**, although the FIG. **23** is not drawn to the same scale as are FIGS. **21** and **22**. FIG. **24** is an enlarged detail view of portions of the optically transmissive member or window, the EL device and the wicking structure, corresponding to that encircled by the arrow B-B in FIG. **23**. Although shaped differently, the EL based light emitting device of FIGS. **21-24** is very similar to the device **41***a* of FIG. **7**A.

The optical/electrical transducer for emitting light includes a thermally conductive metal housing section, an optically transmissive member or window. Similar to the transducer **41***a* of FIG. **7**A, the downlight of FIGS. **21-24** includes an EL device mounted on the optically transmissive member that serves as the light emission window. A heat sink is formed on the exterior of the upper portion of the metal housing section (on the upper surface in the orientation illustrated in FIG. **14**).

In this example, the thermally conductive metal housing section is shown in the form of a rectangular member, with angled sides and a curved upper section. The optically transmissive window is shown in the form a flat plate or the like. Obviously other shapes may be used for the housing section and member. The fixture may be three of four feet long, for example, for replacement of or substitution for a fluorescent light fixture. As in the earlier examples, the optically transmissive member or window is attached to the metal thermally conductive housing section to form a seal for the vapor tight chamber. A hot location/interface is formed at the surface of the EL device exposed within the chamber, and cold locations are formed at the opposite portion of the chamber adjacent the upper region of the metal housing section as well as locations somewhat away from the EL device along lateral regions of the Rousing section.

In this example, the lower element of the electroluminescent device is a transparent conductor formed on the optically transmissive member. A reflective conductive layer may be provided on the opposite surfaced, although in the example, electrical connection to the opposite surface is provided by use of an electrically conductive working fluid. The materials and manner of assembly of the light emitting transducer of FIGS. **21-24** are similar to those of earlier examples. The light emitting transducer of FIGS. **21-24** operates to emit light as well as to dissipate heat, essentially in the same ways as does the EL device based light emitter of FIG. **7**A.

FIG. **25** is a top view, and FIG. **26** is an isometric view, of a device or light engine for emitting light. The illustrated device **301** could be used as a light engine of a light fixture, although the exemplary configuration is particularly configured for use in a lamp or 'light bulb,' for example, in combination with a transparent, translucent or colored transmissive globe (not shown).

As in the earlier examples, the light emitting device **301** may operate at any orientation, although a particular orientation is illustrated for convenience. Some aspects of the following description of the light emitting device **301** use directional terms corresponding to the illustrated orientation, for convenience only. Such directional terms may help with understanding of this description of the example of FIGS. **25-27**B but are not intended to be limiting in any way.

The light emitting device **301** includes a light emitting transducer apparatus that is integrated with a thermal conductivity and phase transition heat transfer mechanism, represented together as one integral element **303** in the drawings. Heat is transferred from the apparatus **303** to a heat sink **305**. The heat sink **305** is formed of a highly thermally conductive material, typically a metal such as copper or aluminum, although other materials, such as thermally conductive plastics and ceramics, may be used. The heat sink **305** in our example has a core **307** having a central passage, a wall of which forms a fairly tight structural and thermal connection to the outer surface of a portion of the housing of the apparatus **303**. The rest of the apparatus **303** extends upward or away from the passage in the core **307** of the heat sink **305**, to form a pedestal or the like with a light emitting diode at or near the distal end. Extending radially outward from the core **307**; the heat sink **305** has a number of fins **309** for radiating heat to the ambient atmosphere. Straight radial fins are shown, for convenience, although other shapes/contours may be used, e.g. to promote heat transfer and/or to allow a desired amount of light from the emitter and phosphor to pass down between the fins.

FIG. **27**A is a cross-sectional view taken along line A-A of FIG. **25**, and FIG. **27**B is an enlarged detail view of a portion of the optical/electrical transducer apparatus **303** and heat sink **305** corresponding to that encircled by the arrow B-B in FIG. **27**A. As illustrated, the light emitting device **301** includes a housing having a section **313** that is thermally conductive and a member **315** that is at least partially optically transmissive. In this example, the thermally conductive section **313** consists of a hollow copper cylinder or tube having a circular cross-section. A substantial portion of the copper section **313** of the housing extends down into the passage through the core **307** of the heat sink **305**. The copper section **313** may be press fitted into the passage or be otherwise connected and thermally coupled to the heat sink **305** in any appropriate manner suitable for efficient heat transfer and to provide structural support that may be necessary for the apparatus **303**. The end of the copper cylinder or tube of section **313** opposite the optically transmissive member **315** is closed, e.g. by a flat circular section of copper.

In this example, the optically transmissive member **315** consists of a hollow glass cylinder or tube having a circular cross-section and closed at one end by a curved or dome-shaped section of the glass. The cylindrical thermally conductive section **313** and the optically transmissive member **315** have approximately the same lateral dimensions so as to form a relatively straight continuous cylinder, although other lateral and cross-sectional shapes could be used. For example, one or both of the elements **313**, **315** could vary in shape and/or dimension along the lateral length of the light emitting transducer apparatus **303**, e.g. so that the region away from the heat sink **305** is somewhat enlarged or bulbous at the end of the pedestal. Also, the distal end of the optically transmissive member **315** (furthest away from the heat sink **305** could have other shapes, e.g. to be flat or concave instead of the illustrated dome shape.

The glass optically transmissive member **315** is connected to the copper thermally conductive section **313** of the light emitting transducer apparatus **303** to form a housing enclosing a vapor chamber and a semiconductor light emitting device. Specifically the section **313** and member **315** are connected so as to form a vapor tight seal for the chamber. The two elements may be joined by a glass frit process or by application of a suitable epoxy, at the glass/copper interface.

Glass and copper are given by way of examples of the materials of the optically transmissive member **315** and the thermally conductive section **313**. Those skilled in the art will appreciate that other optically transmissive materials and thermally conductive materials may be used.

The semiconductor light emitting device in this example includes semiconductor nanowires forming a light emitting diode (LED) **317**, within the chamber. In this example, the semiconductor nanowires thriving the LED **317** are formed or mounted on the curved interior surface at the distal end of the optically transmissive member **315**. The structure of the LED **317** with the nanowires may be similar to the transducer device discussed above relative to FIGS. **1**B and **2**. As noted at one point in the discussion of FIGS. **1**B and **2**, reflectors may be provided at the distal (inner most) ends of the nanowires of the LED device **317**, to increase output of light from the LED through the dome of the glass member **315**. Since the LED **317** is mounted on glass, one or both electrical connections to the LED may be provided by separate leads (two of which are shown in the drawing), in which case, the working fluid need not be conductive.

The glass forming the optically transmissive member **315** may be transparent or translucent or exhibit other transmissive characteristics (e.g. non-white color filtering), depending on the application for the device **301**. The glass of the member **315** permits emission of at least some light from the LED **317** as an output of the light, emitting device **301**.

For purposes of operating as a thermal conductivity and phase transition heat transfer mechanism, the light emitting device **301** also includes a working fluid within the chamber. The working fluid directly contacts the outer surfaces of the nanowires of the LED **317**. The working fluid may also directly contact surfaces of the phosphor. The pressure within the chamber configures the working fluid to absorb heat from the LED **317**, particularly from the nanowires, during operation of the device **301**. The fluid vaporizes at a relatively hot location at or near the semiconductor nanowires of the LED **317** as the working fluid absorbs heat. The vapor transfers heat to and condenses at a relatively cold location of the copper section **313** in contact with the heat sink **305**, and the condensed working fluid returns as a liquid to the relatively hot location at or around the LED **317**.

As in the earlier examples, the device **301** of FIG. **25** includes a wicking structure mounted within the chamber to facilitate flow of condensed liquid of the working fluid from the cold location to the hot location. Together, the housing, the chamber, the working fluid and the wicking structure form a thermal conductivity and phase transition heat transfer mechanism for transferring heat away from the LED **317**, in this case, to the heat sink **305**. The semiconductor nanowires of LED **317** on the inner curved surface of the glass member **315** are configured to serve as a portion of the wicking structure.

In addition to the nanowires of the LED **317**, the wicking structure includes a non-LED (not semiconductor nanowires) wick **321** formed on the portions of the inner surface of the glass member **315** in regions other than the region(s) covered by the structure of the LED **317**. The overall wicking structure further includes a non-LED (not semiconductor nanowires) wick **323** on the inner surface of the copper section **313**. The wicks **321** and **323** may take many forms, as discussed with regard to the earlier examples. The wicks may be similar to each other or different, e.g. as discussed above relative to earlier examples. In the example of FIGS. **25-27**B, the wick in the glass member **315** may be formed of as material that is at least somewhat optically transmissive, whereas the wick in the copper section **313** may be at least somewhat reflective.

Depending, on the application of the light emitting device **301** and/or the light output properties of the LED, the device **301** may or may not include a phosphor or other luminescent material. In the present example, however, the light emitting device **301** does include a phosphor. As outlined earlier, the phosphor may be provided in some or all of the wicking structure. In the example of FIGS. **27**A and **27**B, the phosphor is provided in the form of a layer **325** between the LED **317** and the curved interior surface at the distal end of the optically transmissive member **315** on which the LED is mounted. Light emerging from the LED **317** toward the curved interior surface of the optically transmissive member **315** passes through the phosphor layer **325**. Some of the light excites the phosphor, and the excited phosphor converts optical energy from the LED **317** from energy in one wavelength range (the excitation band of the phosphor) to another wavelength range. For example, the phosphor **325** may convert some energy from the LED **317** from a less desirable wavelength range (e.g. near or outside the visible spectrum) to a more desirable wavelength range (e.g. to fill-in a gap in the spectral characteristic of light produced by the emitter), to improve efficiency of the light emitting device **301** and/or to improve the quality of the light output.

The phosphor layer may include one type of phosphor or phosphor of a number of types, depending on the desired characteristics of the light output of the device **301**. Also, the phosphor layer may extend down the inner surface of the housing, e.g. down the inner cylindrical surface of the glass member **315** to the glass/copper interface. Additional phosphor may be provided in the working fluid.

FIG. **28** is a top view, and FIG. **29** is an isometric view of another device or light engine **301'** for emitting light. FIG. **30**A is a cross section view taken along line A-A of FIG. **28**, and FIG. **30**B is an enlarged detail view of a portion of the optical/electrical transducer apparatus and heat sink of FIG. **30**A, showing the addition of a phosphor layer. The device or light engine **301'** is generally similar to the device **301** of FIGS. **7**-**9**, like reference numerals identity corresponding elements, and the discussion above can be referenced for detailed information about the corresponding elements. The device **301** does include a phosphor. However, instead of including the phosphor as a layer between the light emitting diode and the surface of the optically transmissive member **315**, the phosphor in the device **301'** is carried by the working fluid **325'**. A phosphor hearing working fluid as may be used in the device **301'** has been discussed earlier with regard to the examples of FIGS. **3** and **4**.

FIGS. **25**-**30**B and the descriptions thereof relate to light emitting devices **301**, **301'**. The present teachings are also applicable to transducers that convert optical energy into electrical energy. To appreciate such additional applicability, it may be helpful to consider a specific example of an optical-to-electrical transducer, with reference to FIGS. **31**-**33**B.

FIG. **31** is a top view, and FIG. **32** is an isometric view, eta device **331** for producing an electrical signal in response to light. The device **331** may be configured as an optical energy sensor or detector, e.g. for UV, visible light, infrared, or the like; and/or the device **331** may be configured as a photovoltaic device for generating power in response to optical energy in as desired spectral range. Although not shown, an optically transmissive outer element such as a globe may be added as a cover or the like.

As in the earlier examples, the light responsive transducer device **331** may operate at any orientation, although a particular orientation is illustrated for convenience. Some aspects of the following description of the light transducer device **331** use directional terms corresponding to the illustrated orientation, for convenience only. Such directional terms may help with understanding of this description of the example of FIGS. **31**-**33**B but are not intended to be limiting in any way.

The device **331** includes a light responsive transducer apparatus (including the actual semiconductor transducer, such as a photodiode) that is integrated with a thermal conductivity and phase transition heat transfer mechanism, represented together as one integral element **333** in the drawings. Heat is transferred from the apparatus **333** to a heat sink **335**. The heat sink **335** is formed of a highly thermally conductive material, typically a metal such as copper or aluminum, although other materials, such as thermally conductive plastics and ceramics, may be used. The heat sink **335** in our example has a core **337** having a central passage, a wall of which forms a fairly tight structural and thermal connection to the outer surface of a portion of the housing of the apparatus **333**. The rest of the apparatus **333** extends upward or away from the passage in the core **337** of the heat sink **335**, to form a pedestal or the like with the photodiode or the like at or near the distal end. Extending radially outward from the core **337**, the heat sink **335** has a number of fins **339** for radiating heat to the ambient atmosphere.

FIG. **33**A is a cross-sectional view taken along line A-A of FIG. **31**, and FIG. **33**B is an enlarged detail view of a portion of the optical/electrical transducer apparatus **333** and heat sink **335** corresponding to that encircled by the arrow B-B in FIG. **33**A. As illustrated, the light responsive transducer device **331** includes a housing having a section **343** that is thermally conductive and a member **345** that is at least partially optically transmissive.

In the example of FIGS. **33**A, **33**B, the member **345** is a curved glass element having an inwardly reflective outer surface to form a reflector with respect to the transducer. Various curvatures may be used to concentrate incoming light at the location of the actual semiconductor transducer **347**. Reflectivity can be provided by a coating or other surface treatment at the curved outer surface of the glass member **345** or possibly by total internal reflection of a substantial portion of the incident light.

A separate member could be used as the optically transmissive member as in the examples of FIGS. **25**-**27**B and as shown in the FIG. **32**. In such a case, the reflector would be fitted over the glass member, and the reflector may be solid as shown or may be an open reflector. However, the reflector is omitted from the isometric view of FIG. **32**, for convenience, to more clearly show the portion of the apparatus **333** extending above the heat sink **335**.

In the examples of FIGS. **33**A, **33**B with the solid reflector **345**, a hollowed portion of the glass thrills a portion of the housing of the transducer apparatus **333** with the integral thermal conductivity and phase transition heat transfer mechanism. Stated another way, in this example, the glass of the reflector **345** also serves as the optically transmissive member of the housing. It should be noted that the detail view of FIG. **33**B represents only the portion of the reflector/member **345** encircled by the arrow B-B and does not show the entire reflector **345** (compare to FIG. **33**A).

The thermally conductive section **343** consists of a hollow copper cylinder or tube having a circular cross-section. A substantial portion of the copper section **343** of the housing extends down into the passage through the core **337** of the heat sink **335**. The copper section **343** may be press fitted into the passage or be otherwise connected and thermally coupled to the heat sink **335** in any appropriate manner suitable for efficient heat transfer and to provide structural support, that may be necessary for the apparatus **333**. The end of the copper cylinder or tube of section **343** opposite the optically transmissive member **345** is closed, e.g. by a at circular section of copper.

In this example, the optically transmissive member **345** consists of a hollow cylinder or tube formed within the glass of the reflector **345**. The hollow section has a circular cross-section and is closed, at one end by a curved or dome-shaped contour within the glass. The interior of the cylindrical thermally conductive section **343** and the hollow within the optically transmissive member/reflector **345** have approximately the same lateral dimensions so as to form a relatively straight continuous cylindrical volume for the vapor chamber within the housing. As in the examples of FIGS. **25-30**B, other lateral and longitudinal shapes may be used for either or both of the section **343** and the interior volume of the glass member **345**.

The glass optically transmissive member **345** is connected to the copper thermally conductive section **343** of the light emitting transducer apparatus **333** to form a housing enclosing a vapor chamber and a light responsive semiconductor transducer. Specifically, the section **343** and member **343** are connected so as to form a vapor tight seal for the chamber. The two elements may be joined by a glass frit process or by application of a suitable epoxy, at the glass/copper interface.

Glass and copper are given by way of examples of the materials of the optically transmissive member **345** and the thermally conductive section **343**. Those skilled in the art will appreciate, that other optically transmissive materials and thermally conductive materials may be used.

The apparatus **333** includes a semiconductor transducer that generates an electrical signal in response to light. As shown at **347**, the semiconductor transducer is formed so as to include semiconductor nanowires. The semiconductor transducer may take and of a number of different forms, although for purposes of further discussion, we will assume that the semiconductor transducer **347** is configured as a photovoltaic or the like.

The glass forming the optically transmissive portion of the reflector **345** may be transparent or translucent or exhibit other transmissive characteristics (e.g. non-white color filtering), depending on the photovoltaic or sensor application for the device **331**. The glass of the member **345** permits light directed toward the reflector/member to pass through to the photo voltaic device **347** as an input of the light responsive transducer device **331**. Light impacting on the reflective portion of the member **345** is reflected back through the glass for concentration at the position of the photovoltaic **347**.

As discussed above, the device **331** includes a housing having a section **343** that is thermally conductive and a member **345** that is at least partially optically transmissive; and together, the housing section **343** and the optically transmissive member form a vapor chamber containing the working fluid for the integral thermal conductivity and phase transition heat transfer mechanism.

In this example, the semiconductor nanowires forming the photovoltaic **347** are formed or mounted on the curved interior surface at the distal end of the cavity within the optically transmissive member **345**. The structure of the photovoltaic **347** with the nanowires may be similar to the transducer device discussed above relative to FIG. **2**. As noted in earlier discussions, reflectors may be provided at distal ends of the nanowires, in this case to reduce the amount of light that escapes past the photovoltaic into the rest of the chamber and thus increase the amount of light processed by the photovoltaic **347**. Since the photovoltaic **347** is mounted on glass, one or both electrical connections to the photovoltaic may be provided by separate leads (two of which are shown in the drawing), in which case, the working fluid need not be conductive.

For purposes of operating as a thermal conductivity and phase transition heat transfer mechanism, the light emitting, device **331** also includes a working fluid within the chamber. The working fluid directly contacts the outer surfaces of the nanowires of the photovoltaic **347**. The pressure within the chamber configures the working fluid to absorb heat from the photovoltaic, particularly from the nanowires, during operation of the device **331**, to vaporize at a relatively hot location at or near the semiconductor nanowires of the photovoltaic **347** as the working fluid absorbs heat. The vapor transfers heat to and condenses at a relatively cold location of the copper section **343** in contact with the heat sink **335**, and the condensed working fluid returns as a liquid to the relatively hot location at or around the photovoltaic **347**.

As in the earlier examples, the device **331** of FIGS. **31-33**B includes a wicking structure mounted within the chamber to facilitate flow of condensed liquid of the working fluid from the cold location to the hot location. Together, the housing, the chamber, the working fluid and the wicking structure form a thermal conductivity and phase transition heat transfer mechanism for transferring heat away from the photovoltaic **347**. The semiconductor nanowires of photovoltaic **347** on the inner curved surface of the glass member **345** are configured to serve as a portion of the working structure.

In addition to the nanowires of the photovoltaic **347**, the wicking structure includes a wick **351** formed of non-semiconductor nanowires on the portions of the inner surface of the glass member **345** in regions other than the region(s) covered by the structure of the photovoltaic **347**. The overall wicking structure further includes a wick **353** formed of non-semiconductor nanowires on the inner surface of the copper section **343**. Although formed of nanowires in the example, the wicks **351** and **353** may take many forms, as discussed with regard to the earlier examples. The wicks may be similar to each other or different, e.g. as discussed above relative to the earlier examples. In the example of FIGS. **31-33**B, the wick in the glass member **345** may be formed of a material, that is at least somewhat optically transmissive, whereas the wick in the copper section **343** may be at least somewhat reflective.

The example of FIGS. **31-33**B does not include a phosphor. However, some sensor or photovoltaic applications of the apparatus **331** may include a phosphor. If useful, a phosphor appropriate to the application could be included in any of the various ways discussed above with regard to earlier examples.

Those skilled in the art will appreciate that the teachings above may be applied in a variety of different ways and are not limited to the specific structures, materials and arrangements shown in the drawings and described above. For example, the instructed devices include one transducer with the nanowires forming part of the wick within the chamber of the thermal conductivity and phase transition heat transfer mechanism. It is contemplated that a single device or apparatus may include multiple transducers with the nanowires of the transducers forming part of the wick. In a device having multiple semiconductor transducers, the transducers may be substantially similar, e.g. to emit or sense the same type of light. Alternatively, different transducers in one device may serve multiple purposes. For example, one semiconductor transducer might be configured to sense or emit, light of a first spectral characteristic, whereas another semiconductor transducer might be configured to sense or emit light of a different second spectral characteristic. In another example of a multi-transducer arrangement, one semiconductor transducer might be configured to sense or emit light and another semiconductor transducer might be configured as a sensor of light or temperature.

It should be apparent from the discussion above that when an element is referred to as being "on," "attached" to, "connected" to, "coupled" with "contacting," etc., another element, it can be directly on, attached to, connected to, coupled with or contacting the other element or intervening elements or spacing may also be present. In contrast, when an element is referred to as being, for example, "directly on," "directly attached" to, "directly connected" to, "directly coupled" with or "directly contacting" another element, there are no substantial intervening elements present, although in some cases there may be intervening elements or layers of up to a micron or so, so long as such layers or elements do no substantially reduce thermal conductivity. It will also be appreciated by those of skill in the art that references to a structure or feature that is disposed "adjacent" another feature may have portions that are nearby or even overlap or underlie the adjacent feature.

Similarly, spatially relative terms, such as "under," "below," "lower," "over," "upper" related orientation or directional terms and the like, that may have been used above for case of description to describe one element or feature's relationship to another element(s) or feature(s) orientation or direction as illustrated in the figures. It will be understood that the spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is inverted, elements described as "under" or "beneath" other elements or features would then be oriented "over" the other elements or features.

While the foregoing has described what are considered to be the best mode and/or other examples, it is understood that various modifications may be made therein and that the subject matter disclosed herein may be implemented in various forms and examples, and that the teachings may be applied in numerous applications, only some of which have been described herein. It is intended by the following claims to claim any and all applications, modifications and variations that fall within the true scope of the present teachings.

What is claimed:

1. A thermal conductivity and phase transition heat transfer mechanism comprising:

an integral active optical element to be cooled by phase transition of the mechanism, at least a portion of the active optical element being exposed to a working fluid within a vapor tight chamber of the heat transfer mechanism, the active optical element comprising a phosphor;

a member that is at least partially optically transmissive serving both to seal the working fluid within the chamber and to allow passage of light to or from the active optical element; and

a wicking structure within the chamber, wherein the phosphor is formed in at least a portion of the wicking structure.

2. The mechanism of claim **1**, wherein the phosphor is an opto-luminescent type of phosphor.

3. The mechanism of claim **1**, wherein the phosphor is electroluminescent type of phosphor.

4. A thermal conductivity and phase transition heat transfer mechanism comprising:

an integral active optical element to be cooled by phase transition of the mechanism, at least a portion of the active optical element being exposed to a working fluid within a vapor tight chamber of the heat transfer mechanism; and

a member that is at least partially optically transmissive serving both to seal the working fluid within the chamber and to allow passage of light to or from the active optical element, wherein:

the active optical element comprises an opto-electrical transducer; and

the working fluid is electrically conductive for carrying electrical current to or from a portion of the opto-electrical transducer during operation of the opto-electrical transducer.

5. The mechanism of claim **4**, wherein:

pressure throughout the chamber configures the working fluid to perform a phase transition cycle that moves the fluid and changes states of the fluid so as to absorb heat during operation of the active optical element, to vaporize at a relatively hot location of the mechanism as it absorbs heat, to transfer heat to and condense at a relatively cold location of the mechanism, and to return as a liquid to the relatively hot location of the mechanism; and

the phase transition cycle is performed without power or any mechanical part.

6. The mechanism of claim **4**, wherein the opto-electrical transducer is a light emitter.

7. The mechanism of claim **6**, wherein the light emitter is a type of emitter selected from the group consisting of: a light emitting diode (LED), an organic light emitting diode (OLED), a laser diode, a nanowire light emitter, and an electroluminescent device.

8. The mechanism of claim **4**, wherein the opto-electrical transducer is a light-to electricity converter.

9. The mechanism of claim **8**, wherein the light-to electricity converter is a sensor or a photovoltaic device.

10. The mechanism of claim **4**, further comprising a wicking structure mounted within the chamber to facilitate flow of condensed liquid of the working fluid from the cold location of the mechanism to the hot location of the mechanism.

11. The mechanism of claim **10**, wherein the wicking structure comprises grooves, sintered powder, mesh, wires or nanowires on an inner surface of the chamber.

12. The mechanism of claim **10**, wherein the wicking structure is at least substantially reflective.

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